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# MULTIPURPOSE BENEFITS AND COSTS OF MODIFYING PLAYA LAKES OF THE TEXAS HIGH PLAINS

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International Center for Arid and Semi-Arid Land Studies
Lubbock, Texas

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## ACKNOWLEDGMENTS

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## SUMMARY AND CONCLUSIONS

Unmodified playa lakes of the Texas High Plains are of little benefit to agriculture. Even though the lakes are generally dry, cultivation of lake-bed land is a risk because periodic high-intensity of long-duration rains fill the lakes with a shallow body of water that damages or destroys crops. In the past, water caught by lakes has been of little use to irrigation farmers because evaporation and seepage has practically eliminated the supply of lake water before farmers could put it to productive use.

By modifying playa lakes to concentrate the accumulated runoff water into deep small-surface size modification, lake-bed cropland would be protected from overflow and water could be saved for irrigation use at a later date. In addition, concentrating lake water into deeper but smaller sized lakes benefits the area by reducing the breeding of encephalitis spreading mosquitoes. A physical and an economic analysis of playa lake resources and modification was conducted to determine the economic feasibility of modifying playa lakes of the Texas High Plains. The objectives of this study were to: (1) determine the number, size, and volume of playa lakes in a 27 county High Plains area, (2) estimate costs of selected alternative lake modifications, (3) estimate potential benefits of modification by type and size of lake and intended use, and (4) estimate net benefits to modification. The study area consisted of the fine- and medium-textured soils areas of the Texas High Plains. The fine-textured soils area is essentially the High Plains area north of Bailey, Lamb, Lubbock, and Garza counties. The medium-textured soils area consisted of Bailey, Lamb, Lubbock, Hockley, Cochran, Terry, Lynn and Dawson counties.

It was estimated that the study area had 16,734 playa lakes with 59 percent of lakes (9,939) located in the fine-textured soils area and 41 percent of lakes (6,795) located in the medium-textured soils area. Lakes located in the fine-textured soils area, accounted for 87 percent of the area's estimated 365 thousand acre-feet of total unmodified lake storage capacity. The fine-textured soils area had a larger number of large lakes, and the lakes of this area had larger volumes per unit surface size than lakes of the medium-textured soils area.

The costs of four alternative modification methods were estimated for selected lake sizes (2.5, 8, 15, 25, and 45 acre lakes) in each soil area. Model I modification was a sump dug to facilitate lake-pump suction for direct irrigation from the otherwise unmodified lake. Model II was designed to protect land and save water when half or less than half of the full lake volume was caught; a diversion terrace would direct runoff water into two separate quarter sections of the lake which were enclosed by dykes. During periods, when the lakes are more than half full, Model II would be ineffective at lake-bed land protections. Models III and IV were designed to protect lake-bed land from flooding and save water when full lake volumes were caught. Model III consisted of a circular reservoir (combination excavation-circular dyke) in the lake with a diversion terrace and an inlet channel to divert runoff water into the reservoir. Model IV was a rectangular pit excavated in the lake bottom with the excavated soil spread over the remaining portion of the lake bottom. Water would be diverted into the Model IV pit by means of a bank around the pit, which would direct the water into a formless flume at one side of the pit.

The circular reservoir, Model III, had lowest modification cost of models which protect lake-bed land from flooding, store water, and reduce the breeding of encephalitis spreading mosquitoes. The estimated costs of modifying representative lakes in the fine-textured soils area, using Model III, were $1,369 per lake for 8.0 acre lakes, $2,161 per lake for 15 acre lakes, $3,555 per lake for 25 acre lakes, and $6,242 per lake for 45 acre lakes. Modification cost estimates for the medium-textured soils area were $1,134 per lake for 8.0 acre lakes, $1,872 per lake for 15 acre lakes, and $2,864 per lake for 25 acre lakes. The cost of modifying 2.5 acre lakes was estimated at $590 per lake in both soils areas. The rectangular pit, Model IV,was used for 2.5 acre lakes, since Model III could not be used for technical reasons. Estimated total costs of modifying playas of the fine-textured soils area was $27.6 million. Estimated total cost of modifying playas of the medium-textured soils area was $8.5 million. Estimated cost of modifying playas of the entire study area was $36.1 million. Present worth of 20 years of annual maintenance costs for the study area, calculated at a 6 percent discount rate plus present modification costs was $56.8 million ($43.3

million in the fine-textured soils area and $13.4 in the medium-textured soils area). If the maintenance is carried on for 40 years at a 6 percent discount rate, the present worth of modification and maintenance costs was estimated at $63.4 million--$48.4 million in the fine-textured soils area and $15 million in the medium-textured soils area.

Annual modification benefits to individual farmers were estimated for each lake size and soil area from estimates of (1) the quantity of lake-bed land protected and water saved by each of the four alternative modification models, and (2) the net income per unit of land protected and water saved. Estimated annual net income from lake-bed land was $10.81 per acre in the medium-textured soils area and $10.54 per acre in the fine-textured soils areas, respectively.

Annual net incomes of each modification from (1) protected land and (2) water saved less annual modification maintenance costs were combined to give estimates of annual benefits for each alternative modification. These future annual benefits were discounted to present value at zero, six, and 12 percent discount rates. The present values of the modification lifetime annual benefits minus the modification construction cost provided a basis for selecting from among the alternative modification methods studied, the method which produces maximum net benefits. Benefits estimates were made for both 20 year and 40 year life expectancies of modifications since it is not known at present, how long modifications can be expected to last.

The analysis indicated that modification benefits would exceed modification costs for 15, 25, and 45 acre lakes in the fine-textured soils area, but that benefits were less than costs for 2.5 and 8.0 acre lakes of the fine-textured soils area. Modification costs exceeded modification benefits for all lake sizes studied in the medium-textured soils area. The modification method which had the highest net benefits was the circular reservoir (Model III).

Water collection was estimated to occur in May and September. On the basis of the assumption that water caught in May would be used around August 1, and water caught in September would be used around March 31, it was estimated that circular reservoir modifications would make 150 thousand acre feet of irrigation water available annually from the 10 acre and larger lakes of the fine-textured soils area. It was estimated that the circular reservoir modification would protect 107 thousand acres of lake-bed land in the fine-textured soils area in 10 acre and larger lakes. In comparison, the rectangular pit would protect 124 thousand acres of lake-bed land annually and make 180 thousand acre feet of water available annually from the same lakes of the fine-textured soils area, but this method of modification had lower net benefits than the circular reservoir. Modification construction costs of the rectangular pit exceeded the present value of the benefits of the rectangular pit modification, thus, even though this method of modification was estimated to produce more lake-bed land and water than the circular reservoir, this modification method would not be economically feasible in the study area.

The results of this study indicate that it would be economically feasible to modify lakes larger than 10 acres, in the fine-textured soils area. Undiscounted benefits from modification of these 5,930 playas were estimated at $99.3 million if modifications last 20 years and $189.5 million if modifications last 40 years. Total modification costs for lakes larger than 10 acres in the fine-textured soils area were estimated at $22.5 million. If the water and land benefits stream is discounted at 6 percent per annum, the present worth of the 20 year future annual modification benefits stream would be $47.3 million. The benefit--cost ratio for the estimated 20 year stream of modification benefits of the fine-textured soils area was approximately 2.1 at a discount rate of 6 percent; i.e., benefits were approximately twice the level of modification costs. Present worth of a 40 year land and water benefits stream discounted at 6 percent per annum was estimated at $64.6 million. The benefit-cost ratio for this 40 year benefit stream was estimated at 2.87 when the discount rate was increased to 12 percent the benefit-cost ratio for 20 year modification projects of the fine-textured soils area was estimated at 1.2. The estimated benefit-cost ratio for 40 year modification projects was 1.3 when benefits were discounted at 12 percent.

Benefit-cost ratios for modification of playas in the medium-textured soils area were negative. Estimated undiscounted water and lake-bed land benefits in the medium-textured soils area were minus $2.0 million; i.e. annual water and lake-bed land benefits were less than annual modification maintenance costs for the entire medium-textured soils area. Estimated net benefits for the medium-textured soils area were negative by the amount of modification costs ($8.5 million) plus present worth of unrecovered future annual maintenance costs.

Present worth of the future annual health benefits from playa modification was estimated at $1.12 million in the fine-textured soils area if modification last 20 years and $1.47 million if modifications last 40 years (discounted at 6 percent per annum). These additional benefits would increase the benefit-cost ratios of the fine-textured soils area slightly but would not be sufficient increases to justify modification of lakes less than 10 acres in surface size in the fine-textured soils area. Present worth, at 6 percent discount rate, of health benefits in the medium-textured soils area was estimated at $0.56 million for 20 year modifications and $0.74 million for 40 year modifications. Estimated health benefits combined with water and land benefits would not be sufficient to raise the benefit-cost ratios of the medium-textured soils area to unity.

The analyses of this study show that it would be economically feasible to modify approximately 35 percent of the playas of the Texas High Plains on the basis of water, lake-bed land and health benefits. The lakes which would be profitably modified, according to estimates of this study, are located in the fine-textured soils area and are larger than 10 acres in surface size. At a discount rate of 6 percent, net benefits to modification were estimated at $31 million if modifications last 20 years and $48 million if modifications last 40 years.

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# MULTIPURPOSE BENEFITS AND COSTS OF MODIFYING PLAYA LAKES OF THE TEXAS HIGH PLAINS

Herbert W. Grubb and Don L. Parks[1]

## INTRODUCTION

The surface of the semiarid Texas High Plains region contains numerous shallow depressions which range in size from less than one acre to more than 50 acres. Surface drainage accumulates in the depressions and forms shallow lakes (playas). The playa lakes vary in size and depth depending upon the intensity and duration of rains. At present, the land and water resources of the playa lakes are not developed for productive use. Crops planted in lake-bed land are subject to damage or complete destruction by lake-bed flooding, and because of the large amount of lake surface area per unit volume of playas, these undeveloped lakes are a poor means of storing water in the Texas High Plains region. Consequently, playa lake water is allowed to either percolate into the lake-beds or evaporate into the atmosphere.[2]

Some physical modification of present playa lakes, representing economic investments, is necessary if playa water and land resources are to be made more productive. Modification of present playa lakes to reduce the surface area will reduce the rate of evaporation per unit time and thus increase the quantity of water available for use at a

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[1]Associate Professor, Department of Agricultural Economics, Texas Technological College and Texas Agricultural Experiment Station, and former Graduate Research Assistant, Department of Agricultural Economics, Texas Technological College.

[2]Hauser, V. L., "Hydrology, Conservation and Management of Runoff Water in Playas on the Southern High Plains," Conservation Report No. 8, Agricultural Research Service, U. S. Dept. of Agricultural, Washington, D. C., 1966.

later date. Playa modification will reduce the number of acres per lake and thus, in effect, provide flood protection to cropland which would be inundated in unmodified lakes.

In order to make decisions pertaining to playa modification, lake owners require information about the expected costs of alternative modifications and expected benefits from modification. The purposes of this study were to (1) provide estimates of the number, size, and volume of playa lakes in a 27 county High Plains area, (2) estimate the costs of modifying playa lakes using laternative modification procedures, (3) estimate the potential lake-owner benefits to playa lake modification by type and size of lake and (4) estimate potential net benefits to lake owners from playa lake modification.

The study area was divided into three subareas -- North, Central, and South (Figure 1). The South and Central areas were divided on the basis of soil differences. The South area is primarily medium-textured soils with the southwest portion having some coarse-textured soils. The Central area and the North area are both primarily fine-textured soils, but are separated by the Canadain River basin.[3] The permeability of the predominant soils of the fine-textured soil area ranges from 0.05 to 0.5 inches per hour.[4] The permeability of the medium-textured soils ranges from 0.5 to 1.5 inches per hour.

The topography of the Texas High Plains is flat to gently undulating with a gradual east-southeast slope averaging about 8 feet per mile for the Southern High Plains and a gradual northeastern slope for the northern Texas High Plains.[5] A major portion of the study area is cultivated annually.

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[3]U. S. Soil Conservation Service. A Map of Land Resource Areas of Texas. National Cooperative Soil Survey Program, U. S. Department of Agriculture, Soil Conservation Service, Washington, D. C. 1965.

[4]U. S. Soil Conservation Service, Carson County Soil Survey, U. S. Department of Agriculture, Soil ConservationService, Washington, D. C. 1962, and Bailey County Soil Survey, 1963.

[5]Cronin, J. G., A Summary of the Occurrence and Development of Ground Water in the Southern High Plains, Texas Board of Water Engineers, Bulletin No. 6107, Austin, Texas, 1961.

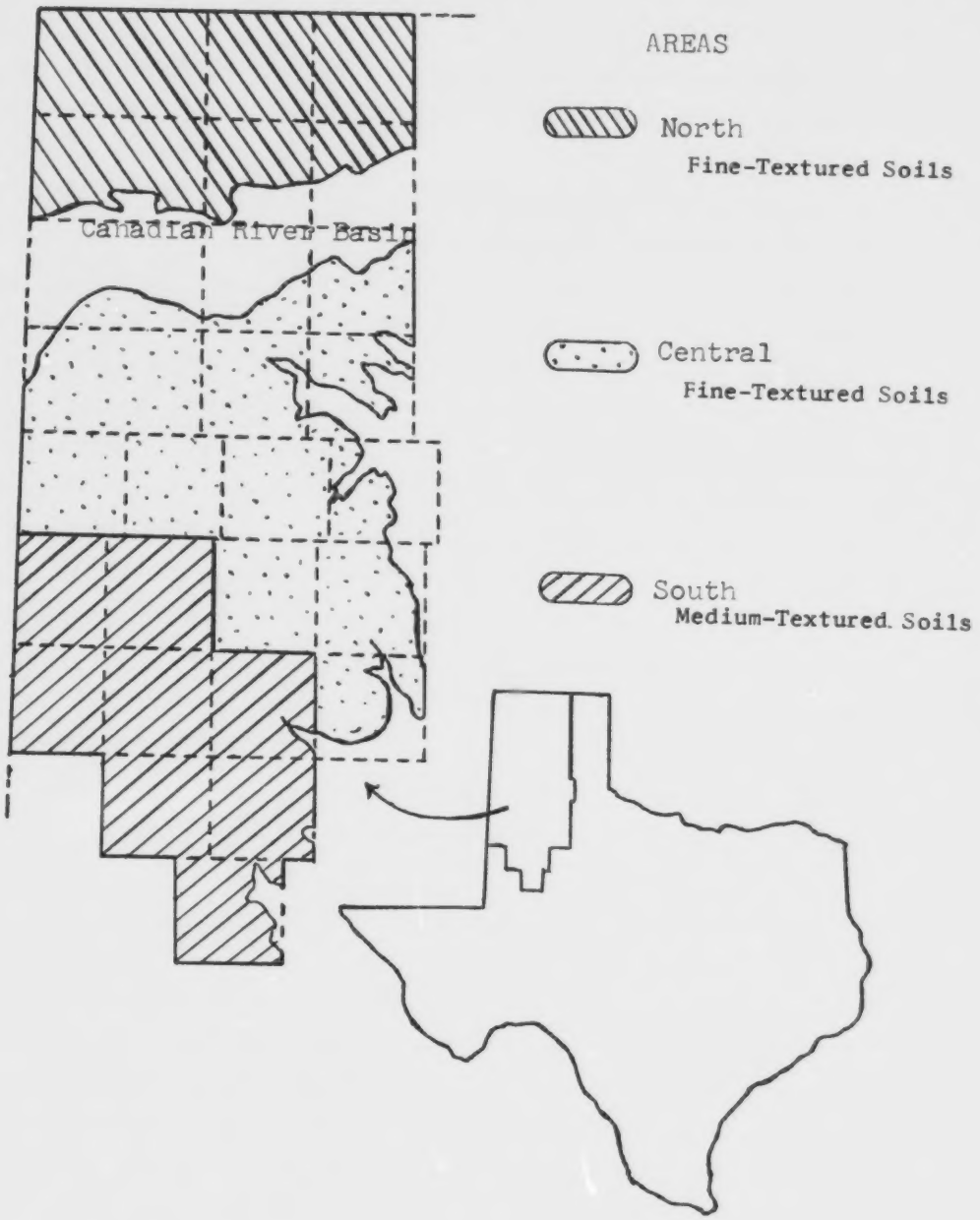


Fig. 1.--Designated Study Area

## METHOD OF ANALYSIS

The analyses of this study involved evaluating costs and benefits from four lake modification designs or models for each of five different lake sizes of the study area (2.5, 15, 25, and 45 acre lakes). Data used in the analyses of this study were obtained from aerial photographs of the study area, a representative sample of lakes, and published research. Aerial photographs were the major source of data used in calculating the number of lakes in each size category per county. The representative sample of lakes was used to develop estimates of volume of lakes per unit surface size. The findings of previous research regarding runoff, infiltration, evaporation, and income from land and water used in cotton and grain sorghum production in the study area were used in calculating estimates of quantity of land protected, quantity of water saved and economic benefits from playa modification. Economic feasibility of playa modification is estimated from comparison of the costs and benefits estimates of modification. The present worth of future net benefits (present worth of gross benefits minus present worth of costs) of each modification method studied were used as the indicator of modification feasibility. Positive present worth of net benefits would indicate that modification would be economically feasible; i.e. that total benefits exceed total costs.

### Modification Cost Estimation

Modification costs are the value of goods and services used in the construction of the modification. Cost estimation required the specification of modification models or designs for each of the four alternative modifications studied, estimation of the quantity of earth to be moved in the construction of each modification and the per unit price of moving earth. Four alternative designs were studied: (1) sump, (2) dyked lake, (3) circular reservoir and (4) rectangular pit. Each modification design implicity specified data on the quantity of earth moved. Earth-moving cost data were obtained from local area commercial earth movers.

## Modification Benefit Estimation

Modification benefits are the value of goods and services made available to individuals by the modification. Individual lake owners can expect to realize modification benefits through increased incomes from lake-bed cropland protection and water savings.[6]

### Annual Land Benefits

Annual benefits from playa lake-bed cropland are the estimated increases in annual net farm income from productive use of lake-bed land protected from flooding. Playa lake-bed land is marginal land in the Texas High Plains in the sense that additional land made available to farms would be farmed as dryland since present study area irrigation water supplies are not sufficient to irrigate the total supply of land in the study area. Additional cropland would be restricted to crops not prohibited by present crop allotment programs of the U.S. Department of Agriculture.

Annual net return per acre of land used in dryland grain sorghum production was selected to represent the expected annual net returns to land from additional acres put into production in the study area, since dryland grain sorghum is the crop which would in effect be produced on net new land made available by playa modification. Dryland grain sorghum is the marginal crop, or is the crop which would be used on additional dryland acres, since it is one of the few crops suitable for dryland conditions of the area. Other crops more profitable than dryland grain sorghum, including irrigated vegetables, can be produced on playa lake-bed land, but under present allotment programs, and because of a shortage of irrigation water, an increase in the production of such crops on High Plains farms would simply result in a shifting of present dryland grain sorghum acreages onto other dryland acres within the same farm or in shifting irrigated acres

[6] Additional benefits to playa modification in the form of reduced encephalitis in the study area were estimated in Benefits and Costs of Modifying Playa Lakes to Reduce Encephalitis in the Texas High Plains, Texas Technological College, February, 1968, Grubb, H. W., Parks, D. L., and Sciple, G. W.

into dryland grain sorghum production. For these reasons, dryland grain sorghum income is the appropriate basis for estimating the value of additional land made available through playa modification.

Annual Water Benefits

Annual water benefits from playa modification are the annual net farm incomes from irrigation water made available by the modifications. The quantity of water involved, the time it is caught and the crops irrigated have a bearing upon ultimate water benefits. Due to study area rainfall patterns, playa modifications would be expected to catch water during May and June and during September and October. Water caught in September and October would be used in preplant irrigation around March 1 of the following year. Water caught in May and June would most likely be used during the critical period of the irrigation season to supplement the present irrigation water supply.

In the study area, the critical period of the irrigation season is approximately August 1; the time at which evapotranspiration is high due to advanced stages of plant growth and crop maturing processes. At this time of the irrigation season, the quantity of water available from irrigation wells per day is lower than at earlier periods of the irrigation season because continued pumping results in a water table cone of depression surrounding each well. Whenever possible, farmers would use additional water, such as that made available through playa modification, to irrigate additional acres during the critical period of the irrigation season, since irrigation wells would irrigate fewer acres at that time than could be irrigated during earlier periods of the irrigation season.

Cotton was chosen as the crop through which to market water in the medium-textured soils area since cotton is the major high valued irrigated crop of that area; i.e. returns from additional water would be highest, on an area-wide basis, if the water were used to irrigate cotton. Grain sorghum was chosen as the crop through which to market water in the fine-textured soils area, since grain sorghum is the major irrigated crop for that area. On the average, additional water would

be expected to return higher net farm income in grain sorghum irrigation in the fine-textured soils area than in irrigation of other crops.

Annual water benefits from playa modification in the medium-textured soils area were the average annual net farm incomes per acre foot of water applied to cotton, after all other expenses were paid including a cost for land and farm management equal to expected income to land and farm management under dryland conditions. Annual farm income per acre foot of irrigation water made available by playa modification was estimated by calculating the difference between net farm income per acre of dryland cotton and net farm income per acre of irrigated cotton. This difference was then expressed per acre foot of water used in cotton irrigation.

Annual water benefits from playa modification in the fine-textured soils area were the average annual net farm income per acre foot of water applied to grain sorghum. The calculation procedures used to estimate annual water benefits were the same as those outlined above for the medium-textured soils area.

Net Benefits Estimation

The estimated benefits and costs of alternative modifications for the four lake sizes considered were compared on a benefit minus cost, or a net benefit basis. Since benefits would be realized in future years, or benefits would be deferred and investment capital has an opportunity cost greater than zero, the future benefits were expressed in present value for meaningful benefit cost comparisons in present time. Present values of future net benefits were calculated by discounting future net benefits at various discount rates selected to represent a variety of viewpoints pertaining to the present value of future income.[7] Private investment objectives would likely be such that alternative investments would be compared on the basis of present value of expected future net incomes. The particular modification which yielded highest present

[7] In this study, discount rates used are not necessarily interest rates for loans, but instead, the discount rates are indicative of the time preference factors associated with future income.

value net benefits would be selected as the most attractive investment alternative among the modifications considered in this study. In addition, the present worth of future benefit streams calculated at various discount rates permits playa modification projects to be compared with other investment opportunities, and provides a test of the sensitivity of playa modification feasibility to the discount rate.

## Assumptions Underlying the Analysis

The major critical assumptions that were adhered to in this analysis and that made the analysis relevant were as follows:

1. Playa lakes were symmetrical from the center.

2. The lake high-water mark, characterized by vegetative debris, a change in soil type, and a change in the nature and types of vegetation, was used to identify the surface size and the volume of sample lakes when full.

3. An annual rainfall greater than 25 inches would result in unmodified lakes obtaining a volume greater than the high-water-mark volume.

4. Plants in the lake bed would cause evaporation to decrease, but in such cases transpiration would increase by an offsetting amount.

5. Seepage water losses of the lakes in the fine-textured soil area would be 15 percent and in the medium-textured soil area would be 60 percent of the total water loss.[8]

6. The water seepage loss per unit of water surface area would be equal for modified and unmodified lakes on the same site.

7. The lake water saved by modification would be used to supplement, rather than substitute for other sources of irrigation water.

8. The soil of modified playas would have equal fertility to soil surrounding the lake.

9. The 1966 production technology and the 1966 product and factor prices were held constant through time.

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[8] Hauser, V. L., Hydrology, Conservation and Management of Runoff Water in Playas on the Southern High Plains, Conservation Research Report No. 8, ARS, USDA, Washington, D. C., 1966.

10. Average annual net return to cultivated unmodified lake-bed land would be zero.

Playa lake-beds are characterized by a unique soil--the Randall Series. Randall soil is a dark gray clayer soil with a high percentage of montmorillonite clay, which has a high shrink-swell capacity. The clay soil occupies the area below the high-water mark, and has a depth of from six feet to twenty or more feet. The soil becomes sticky and plastic when wet and because of the montmorillonite clay, the permeability is very low. Very little water passes through the sediment which has collected in the lakes of the fine-textured soils area.[9] Lakes in the medium-textured soil area have a much higher infiltration rate than lakes in the fine-textured soils area.

## NUMBER, SIZE AND VOLUME OF HIGH PLAINS PLAYA LAKES

The number, size and volume of playa lakes was estimated from aerial photographs of the study area, topographic maps and a representative sample of playa lakes. An actual count of playas from aerial photographs and topographic maps showed a total of 16,734 lakes in the study area (Table 4). Fifty-nine percent of total playas are located in the fine-textured soils area and the remaining 41 percent are located in the medium-textured soils area. Approximately 29 percent of playa lakes of the study area were less than five acres in surface size and 50.8 percent were less than 10 acres in size. Only 5.6 percent of playas of the study area were in excess of 50 acres in surface size. Average surface size of lakes in the fine-textured soil area is larger than average surface size of lakes in the medium-textured soil area. The greatest concentration of lakes per unit land area is in a 40 mile wide band along either side of the dividing boundary between the fine and the medium-textured soils area (central and south dividing line of Figure 1).

Regression analysis was used to relate volume of lakes to surface size of lakes in each of the major soil areas of the study area. The estimated equations are shown in Figure 2. These equations were used

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[9] Cronin, J. G., A Summary of the Occurrence and Development of Ground Water in the Southern High Plains, Texas Board of Water Engineers, Bulletin 6107, Austin,Texas, 1961

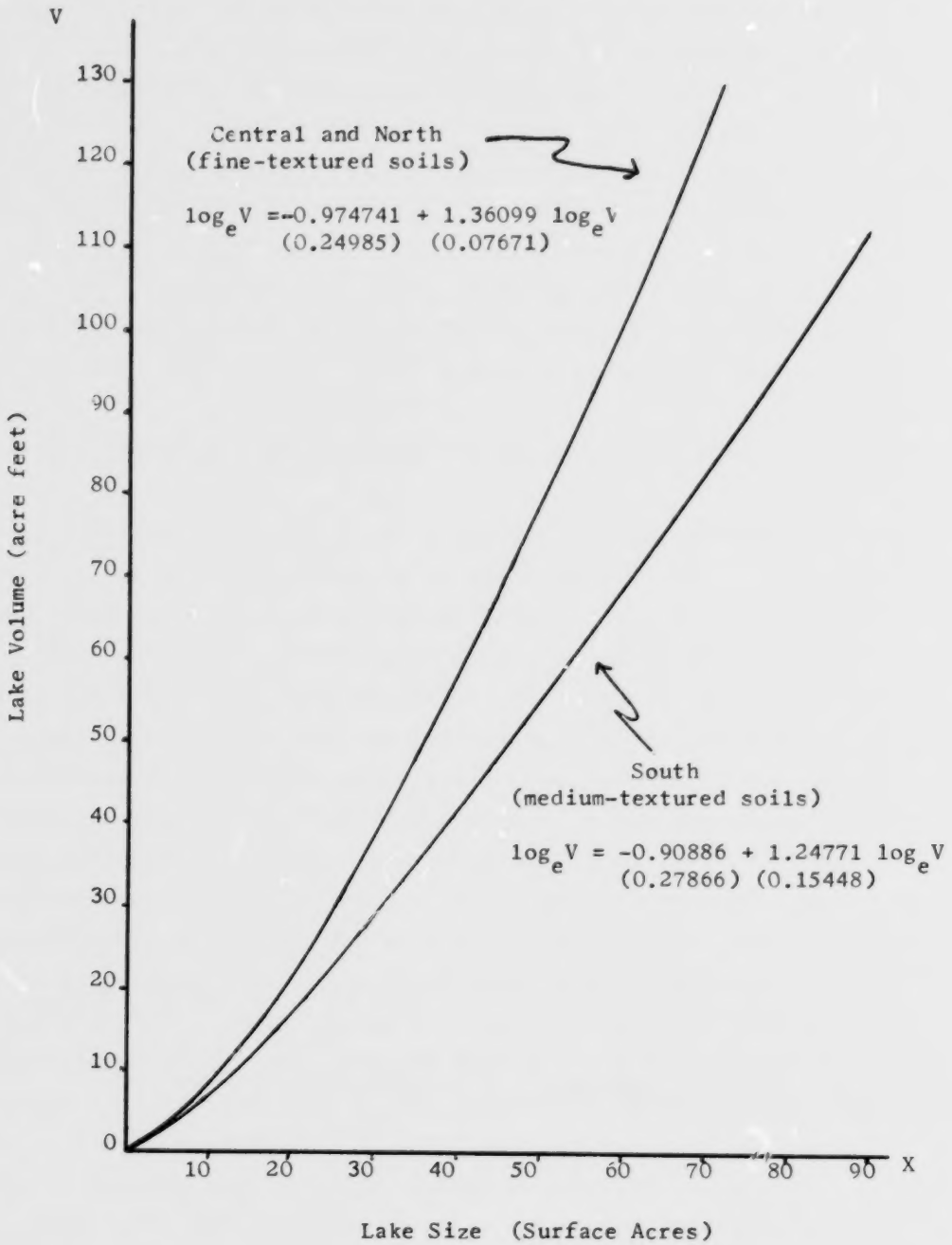


Figure 2.--Volume Size Relationships by Subareas--Texas High Plains

TABLE 1. -- Number of Playa Lakes: North Plains

| County | Size in Acres[a] | | | | | | | | County Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0-4.99 | 5-9.99 | 10-14.99 | 15-19.99 | 20-29.99 | 30-39.99 | 40-49.99 | 50- | |
| Dallam[c] | 88 | 53 | 33 | 22 | 9 | 7 | 4 | 19 | 235 |
| Hansford[b] | 99 | 64 | 65 | 27 | 29 | 21 | 12 | 28 | 345 |
| Hartley[c] | 92 | 61 | 35 | 22 | 13 | 17 | 5 | 18 | 263 |
| Hutchinson[c] | 33 | 37 | 21 | 24 | 19 | 6 | 2 | 10 | 152 |
| Moore[c] | 64 | 27 | 22 | 9 | 15 | 12 | 7 | 31 | 187 |
| Sherman[c] | 62 | 44 | 33 | 20 | 15 | 10 | 8 | 20 | 212 |
| TOTALS | 438 | 286 | 209 | 124 | 100 | 73 | 38 | 126 | 1,394 |

[a]Lakes were grouped according to surface acre size of Randall Clay, Randall fine sandy loam or Randall loamy fine sand from soil maps and according to surface acre size of the depression bottom from topographic maps (see footnotes below); i.e., if the lake has 7.2 acres of Randall clay soil, it was included in the (5-9.99) acre size category.

[b]Actual count from published soil conservation surveys covering 100 percent of county.

[c]Actual count from soil map aerial photographs in county soil conservation service offices.

TABLE 2.---Number of Playa Lakes; Central Plains

| County | Size in Acres[a] | | | | | | | | County Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0-4.99 | 5-9.99 | 10-14.99 | 15-19.99 | 20-29.99 | 30-39.99 | 40-49.99 | 50- | |
| Armstrong[c] | 277 | 116 | 63 | 41 | 34 | 15 | 17 | 65 | 628 |
| Briscoe[e] | 255 | 112 | 56 | 50 | 31 | 14 | 9 | 16 | 543 |
| Carson[b] | 149 | 112 | 54 | 39 | 41 | 26 | 10 | 106 | 537 |
| Castro[d] | 26 | 55 | 74 | 89 | 84 | 92 | 72 | 115 | 607 |
| Crosby[b] | 187 | 194 | 118 | 86 | 120 | 86 | 56 | 74 | 921 |
| Deaf Smith[d] | 68 | 63 | 22 | 30 | 39 | 39 | 34 | 67 | 362 |
| Floyd[d] | 302 | 383 | 268 | 200 | 220 | 137 | 80 | 103 | 1,693 |
| Hale[d] | 88 | 168 | 199 | 189 | 271 | 181 | 49 | 27 | 1,172 |
| Oldham[g] | 15 | 13 | 5 | 6 | 8 | 8 | 7 | 14 | 76 |
| Parmer[d] | 46 | 67 | 82 | 81 | 73 | 40 | 16 | 15 | 420 |
| Potter[c] | 40 | 9 | 10 | 2 | 5 | 2 | 4 | 21 | 93 |
| Randall[c] | 127 | 61 | 48 | 32 | 42 | 27 | 21 | 87 | 445 |
| Swisher[f] | 152 | 200 | 131 | 109 | 173 | 122 | 89 | 72 | 1,048 |
| TOTAL | 1,732 | 1,553 | 1,130 | 954 | 1,141 | 789 | 464 | 782 | 8,545 |

[a]Lakes were grouped according to surface acre size of Randall clay, Randall fine sandy loam or Randall loamy fine sand from soil maps and according to surface acre size of the depression bottom from topographic maps (See footnotes below); i.e., if the lake has 7.2 acres of Randall clay soil, it was included in the (5-9.99) acre size category.

[b]Actual count from published Soil Conservation Surveys covering 100 percent of county.

[c]Actual count from topographic maps covering 100 percent of county.

[d]Actual count from soil map aerial photographs in the county Soil Conservation Service Office (100 percent of county covered).

[e]Actual count from topographic maps for sample of county with sample expanded to 100 percent of county (82.8 percent of Briscoe sampled).

[f]Actual count from soil map aerial photographs in county SCS office for sample of county: this sample expanded to 100 percent of county (70.4 percent of Swisher sampled).

[g]The area of Oldham County having lakes is 0.22 the size of Deaf Smith County area having lakes. This coefficient was used along with the number of lakes in each size category of Deaf Smith County to estimate the number of lakes in Oldham County.

TABLE 3.--Number of Playa Lakes; South Plains

| County | Size in Acres[a] | | | | | | | | County Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0-4.99 | 5-9.99 | 10-14.99 | 15-19.99 | 20-29.99 | 30-39.99 | 40-49.99 | 50- | |
| Bailey[b] | 233 | 159 | 114 | 56 | 34 | 8 | 1 | 9 | 614 |
| Cochran[b] | 280 | 97 | 28 | 3 | 1 | 0 | 0 | 0 | 409 |
| Dawson[b] | 403 | 239 | 118 | 83 | 51 | 21 | 11 | 9 | 935 |
| Hockely[b] | 413 | 356 | 267 | 85 | 40 | 11 | 2 | 3 | 1,177 |
| Lamb[b] | 469 | 281 | 249 | 108 | 107 | 51 | 14 | 8 | 1,287 |
| Lubbock[c] | 405 | 241 | 141 | 72 | 48 | 10 | 4 | 1 | 922 |
| Lynn[b] | 187 | 310 | 180 | 110 | 99 | 26 | 9 | 6 | 927 |
| Terry[b] | 239 | 194 | 77 | 11 | 3 | 0 | 0 | 0 | 524 |
| TOTAL | 2,629 | 1,877 | 1,174 | 528 | 383 | 127 | 41 | 36 | 6,795 |

[a]Lakes were grouped according to surface acre size of Randall clay, Randall fine sandly loam or Randall loamy fine sand from soil maps and according to surface acre size of the depression bottom from topographic maps (see footnotes below); i.e., if the lake has 7.2 acres of Randall clay soil, it was included in the (5-9.99) size category.

[b]Actual count from published Soil Conservation Surveys covering 100 percent of county.

[c]Actual count from topographic maps covering 100 percent of county.

TABLE 4: -- Number of Playa Lakes: Texas High Plains

| Area | Size in Acres | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0-4.99 | 5-9.99 | 10-14.99 | 15-19.99 | 20-29.99 | 30-39.99 | 40-49.99 | 50- | |
| North | 438 | 286 | 209 | 124 | 100 | 73 | 38 | 126 | 1,394 |
| Central | 1,732 | 1,553 | 1,130 | 954 | 1,141 | 789 | 464 | 782 | 8,545 |
| South | 2,629 | 1,877 | 1,174 | 528 | 383 | 127 | 41 | 36 | 6,795 |
| TOTAL | 4,799 | 3,716 | 2,513 | 1,606 | 1,624 | 989 | 543 | 944 | 16,734 |
| Percent of Total | 28.6 | 22.2 | 15.0 | 9.6 | 9.7 | 5.9 | 3.2 | 5.6 | 100 |

in calculating estimates of total volume of playa lakes of the study area, when playa lakes are filled to the lake-bed perimeter on high-water mark (Table 5). The equations of Figure 2 were also used in the calculation of estimates of modification sizes for purposes of making modification cost estimates for representative lakes of the study area.

The total annual quantity of water caught in playa lakes depends upon frequency of filling of playa lakes. The filling frequencies used in this study were based on historical rainfall data for the study area and observed filling time-volume data for playa lake on the Texas Technological College farm.[10] On the basis of these data it was estimated that during a three year period, lakes would catch one-fourth volume twice and three-fourths volume once. The data indicated that lakes could be expected to catch one full volume annually five years of six and one overflow volume one year of six.

Rainfall data for the study area indicate that May and September would be the months during which lakes catch one full volume and that full lake catchment would occur twice as frequently during May as during September due to more frequent high intensity rains in the spring and higher antecedent-soil mositure conditions in the spring than in the fall. High antecedent-soil-moisture conditions can be expected to result in greater quantities of runoff as compared to low antecedent-soil moisture conditions.[11]

## PLAYA MODIFICATION COSTS

Costs were estimated for four alternative modification techniques or models for each representative lake size studied. The modification models were (I) sump, (II) dykes in the lake-bed, (III) circular reservoir, and (IV) rectangular pit. A detailed description of each modification

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[10] Dvoracek, M. J., Unpublished data, Department of Agricultural Engineering, Texas Technological College, Lubbock, Texas, 1965.

[11] Andrews, R. G., "Runoff Estimates Based on Infiltration Capacity, Antecedent Moisture Conditions, and Precipitation," Agricultural Engineering, Vol. 1, No. 1.

TABLE 5.--Estimated Volume of Unmodified Playa Lakes of the Study Area When Lakes Are Full.[a]

| Area | Size in Acres | | | | | | | | Area Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0-4.99 | 5-9.99 | 10-14.99 | 15-19.99 | 20-29.99 | 30-39.99 | 40-49.99 | 50. | |
| | (acre feet) | | | | | | | | |
| North | 574 | 1,676 | 2,445 | 2,294 | 3,010 | 342 | 2,550 | 29,702[b] | 42,593 |
| Central | 2,269 | 9,101 | 13,221 | 17,649 | 34,344 | 35,635 | 31,134 | 128,483[b] | 273,836 |
| South | 3,312 | 9,347 | 11,059 | 7,550 | 8,579 | 4,318 | 1,911 | 2,617[c] | 48,693 |
| High Plains Total | 6,155 | 20,124 | 26,725 | 27,493 | 45,933 | 42,295 | 35,595 | 160,802 | 365,122 |

[a]Volume is estimated from equations of Figure 2 and lake numbers of Tables 1, 2, and 3 of the text. Total volume in a typical size category of each subarea is number of lakes in that size category times the estimated volume of the representative lake. The representative lake of each size category is the lake having the midpoint size; i.e. for the 10-14.99 size lakes, the representative lake is 12.5 acres.

[b]Same as "a" but X equals 86.9 acres.

[c]Same as "a" but X equals 64.3 acres.

along with the formulas for calculating volume of earth contained in each modification, is presented in Appendix C. Representative lake sizes for which modifications were evaluated are shown in Table 6.

Model I, the sump, is a minimal type modification which is designed to permit pumping lake water back onto the land as early as possible after lake filling. This modification method is expected to provide some protection to crops planted in the lake-bed since the lake would originally be emptied before flood damage to crops would occur. This modification would not provide water storage.

Model II, the dyked lake-bed, is designed to reduce the surface size of the lake-bed by diverting runoff around the lake and into one dyke--enclosed section of the lake-bed (Appendix C, Model II). This modification would protect crops planted in the lake-bed only for storms which did not fill the entire lake; i.e. the capacity of the dyked sections are less than a full lake volume. Modification Model II would store water for later use and thus affords some benefits to both land and water resources of playa lakes.

The circular reservoir, Model III, is designed to contain one full lake volume within approximately two-tenths of the unmodified lake surface area. Runoff would be channelled around the unmodified part of the lake-bed and into the circular reservoir by a contour terrace constructed at the modification crest elevation (Appendix C, Model III). This model would protect the lake-bed from flooding and would store water for later use, thus producing both land and water benefits.

The rectangular pit, Model IV, is designed to contain one full lake volume in one-tenth of the surface of the unmodified lake-bed but unlike the ciruclar reservoir, runoff would enter this modification directly from the unmodified lake-bed through a paved flume located at the modification perimeter. Although runoff would pass over the unmodified lake-bed, flood damage to crops planted there would be minor. This modification would be expected to produce benefits to both land and water, since the modification would store water for later use.

TABLE 6.--Estimated Quantity of Earth to Be Moved Per Modification Model and Lake Size; Texas High Plains.[a]

| Soil Area | Lake Size | Model I | | Model II | | Model III | | Model IV |
|---|---|---|---|---|---|---|---|---|
| | | Sump | Drainage Ditch | Dykes | Terrace | Circular Reservoir | Terrace Channel | Rectangular Pit |
| | (acres) | (cubic yards) | | | | | | |
| Fine-Textured | 8 | 6 | 42 | 835 | 1,203 | 2,859 | 3,363 | 10,309 |
| | 15 | 6 | 51 | 1,101 | 1,747 | 5,236 | 4,585 | 24,941 |
| | 25 | 9 | 122 | 1,795 | 3,367 | 8,653 | 7,504 | 50,013 |
| | 45 | 13 | 279 | 3,046 | 6,291 | 15,239 | 13,134 | 108,254 |
| Medium-Textured | 8 | 5 | 30 | 750 | 1,203 | 2,402 | 2,751 | 8,712 |
| | 15 | 4 | 35 | 973 | 1,747 | 4,884 | 3,268 | 19,037 |
| | 25 | 5 | 62 | 1,387 | 3,367 | 6,017 | 6,818 | 36,139 |

[a]Formulas for calculating volume of earth in each modification are found in Appendix C.

## Modification Construction and Maintenance Costs Per Lake

The construction costs of Model I were computed on an hourly basis because of the small volume of earth moved. The costs of a dozer and blade to dig the sump were $12.50 per hour. The cost for Modification Model I ranged from $25 to $50 per lake (Table 7).

TABLE 7. Estimated Modification Costs per Representative Lake, by Alternative Modification Methods; Texas High Plains, 1967[a]

| Soil Area | Lake Size | Sump | Dyked Lake | Circular Reservoir | Rectangular Pit |
|---|---|---|---|---|---|
| | | Model I | Model II | Model III | Model IV |
| | (acres) | (dollars) | | | |
| Fine-Textured | 2.5 | 25 | NA | NA | 590 |
| | 8.0 | 25 | 448 | 1,369 | 2,795 |
| | 15.0 | 25 | 627 | 2,161 | 6,666 |
| | 25.0 | 30 | 1,136 | 3,555 | 13,264 |
| | 45.0 | 50 | 2,054 | 6,242 | 28,591 |
| Medium-Textured | 2.5 | 25 | NA | NA | 590 |
| | 8.0 | 25 | 430 | 1,134 | 2,380 |
| | 15.0 | 25 | 598 | 1,872 | 5,131 |
| | 25.0 | 30 | 1,046 | 2,864 | 9,657 |

[a]Modification costs include the costs of earth moving and water intake constructions. Modification costs for Model I were calculated at $12.50 per hour. Earth moving costs were $0.22 per cubic yard for Models II and III and $0.26 per cubic yard for Model IV. Cost per lake is number of cubic yards of earth (Table 6) times earth moving costs per cubic yard.

NA = not applicable

Construction costs of Modification models II, III, and IV were estimated on the basis of the cost per cubic yard of earth moved. The Model IV modification required spreading the excavated soil--a cost not incurred in other modifications studied. It was assumed that excavated soil would be spread over the lake bottom.

Total construction cost estimates for each alternative modification model are presented in Table 7 on a per lake basis; i.e. the cost of

modifying each lake size studied using each modification method is presented in Table 7. The cost of modifying eight acre lakes in the fine textured soils is estimated at $25 using Model I and $1369 using Model II. Modification Model III, circular reservoir, had the lowest cost per lake for modification models which yield both land and water benefits, however this modification method is not applicable to lakes smaller than five acres, since it would be difficult to construct a functional diversion terrace to channel the runoff into the modification.

Annual maintenance cost of each modification was estimated at five percent of modification construction cost. Data were not available to estimate the life expectancy of the four modification models considered, but for purposes of comparing the effect of length of modification life on modification benefits, 20 and 40 year life spans were evaluated.

## Modification Cost--Total Study Area

The costs of modifications for 2.5, 8, 15, 25 and 45 acre lakes were assumed to be representative of the cost of modifications for 0-5, 5-10, 10-20, 20-30, and over 30 acre lakes, respectively. The estimated cost of modifying each of the representative sizes of lakes, by each modification method studied, was applied to the number of lakes in each size category in order to obtain estimates of playa modification costs in the total study area; i.e., the estimated cost of modifying an eight acre lake was applied to the number of lakes in the 5-10 acre size category to obtain an estimate of the cost of modifying the total number of lakes of this size in the study area (Table 8). The estimated total costs of modifying the study area playas by each modification method studied are compared in Table 8. For example, if the rectangular pit were used to modify the study area playas the estimated modification cost is $124 million. If the circular reservoir is used, the estimated cost if modifying all lakes greater than five acres is $33 million. Modification cost comparisons for each size category studied are also shown in Table 8.

TABLE 8.--Estimated Costs of Modifying the Playas of the Texas High Plains by Alternative Modification Method; 1967[a]

| Soil Area | Lake Size | Number of Lakes | Modification Cost | | | |
|---|---|---|---|---|---|---|
| | | | Sump | Dyked Lake | Circular Reservoir | Rectangular Pit |
| | (acres) | | (1000 dollars) | | | |
| Fine-Textured | 0-5 | 2,170 | NA | NA | NA[b] | 1,280 |
| | 5-10 | 1,839 | 46 | 824 | 2,517 | 5,140 |
| | 10-20 | 2,417 | 60 | 1,515 | 5,223 | 16,112 |
| | 20-30 | 1,241 | 37 | 1,410 | 4,412 | 16,360 |
| | 30+ | 2,272 | 114 | 4,667 | 14,182 | 64,959 |
| Total | | 9,939 | 257 | 8,416 | 26,334 | 103,951 |
| Medium-Textured | 0-5 | 2,629 | NA | NA | NA | 1,551 |
| | 5-10 | 1,877 | 47 | 807 | 2,129 | 4,467 |
| | 10-20 | 1,702 | 43 | 1,018 | 3,186 | 8,773 |
| | 20+ | 587 | 17 | 614 | 1,681 | 5,669 |
| Total | | 6,795 | 107 | 2,439 | 6,996 | 20,420 |
| TOTAL | | 16,734 | 364 | 10,855 | 33,330 | 124,371 |

[a]Modification costs include costs of earth moving and water intake constructions.

[b]The reservoir is not applicable for lakes under five acres because lake basin depths are too shallow for diversion terraces to be effective in draining the water into the circular reservoir.

Total cost of modifying study area playas to realize multipurpose benefits including benefits from lake-bed land, irrigation water and reduction of encephalitis spreading mosquitoes was estimated at $36 million.[12] The modification methods required would be the circular reservoir (Model III) for lakes larger than five acres and the rectangular pit (Model IV) for lakes five acres and smaller (Table 8). The present worth of estimated future maintenance costs for both 20 year and 40 year periods plus construction modification construction costs are shown in Table 9 for each modification method studied. These combined maintenance and construction costs for modification that would produce multipurpose benefits calculated at 6 percent discount rate were estimated at $56.9 million if modifications last 20 years and $63.4 million if modifications last 40 years. This is to say, that if area-wide multipurpose playa modification were undertaken in the High Plains, the estimated present outlay would be $36 million and the present worth of the associated future maintenance obligation would be $20.9 million if modifications last 20 years and $27.4 million if modifications last 40 years. Expressed in another way, the costs of multipurpose modification would require $36 million in construction outlay at present and $20.9 million in present reserves to meet the future 20 year estimated maintenance costs.

## PLAYA MODIFICATION BENEFITS

Benefits from playa modification were estimated on the basis of the expected net incomes from use of the increased quantity of playa water and land resources in agricultural production. The estimates of physical quantities of water and lake-bed land involved in playa modification along with estimated modification benefits are presented below.

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[12] Grubb, H. W., Parks, D. L. and Sciple, G. W., "Benefits and Costs of Modifying Playa Lakes to Reduce Encephalitis in the Texas High Plains," Texas Technological College, Lubbock, Texas, February, 1968.

TABLE 9.--Estimated Playa Modification Cost Plus Present Value of Future Maintenance Cost; Texas High Plains 1967[a]

| Soil Area | Lake Size (acres) | Number of Lakes | 20 Years | | | | 40 Years | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sump | Dyked Lake | Circular Reservoir | Rectangular Pit | Sump | Dyked Lake | Circular Reservoir | Rectangular Pit |
| | | | (1000 Dollars) | | | | | | | |
| Fine-Textured | 0-5 | 2,170 | NA | NA | NA | 2,014 | NA | NA | NA | 2,243 |
| | 5-10 | 1,839 | 72 | 1,296 | 3,961 | 8,088 | 81 | 1,444 | 4,411 | 9,007 |
| | 10-20 | 2,417 | 95 | 2,384 | 8,218 | 25,352 | 105 | 2,655 | 9,153 | 28,233 |
| | 20-30 | 1,241 | 58 | 2,219 | 6,942 | 25,903 | 65 | 2,470 | 7,731 | 28,844 |
| | 30+ | 2,272 | 179 | 7,343 | 22,315 | 101,849 | 200 | 10,648 | 24,851 | 113,828 |
| Total | | 9,939 | 404 | 13,242 | 41,436 | 163,567 | 451 | 14,747 | 46,146 | 182,155 |
| Medium-Textured | 0-5 | 2,629 | NA | NA | NA | 2,441 | NA | NA | NA | 2,718 |
| | 5-10 | 1,877 | 74 | 1,270 | 3,350 | 7,029 | 82 | 1,414 | 3,730 | 7,828 |
| | 10-20 | 1,702 | 67 | 1,602 | 5,013 | 13,741 | 75 | 1,784 | 5,583 | 15,303 |
| | 20+ | 587 | 28 | 966 | 2,645 | 8,920 | 30 | 1,076 | 2,846 | 9,934 |
| Total | | 6,795 | 169 | 3,838 | 11,008 | 32,131 | 187 | 4,274 | 12,259 | 35,783 |
| TOTAL | | 16,734 | 573 | 17,080 | 52,444 | 195,698 | 638 | 19,021 | 58,405 | 217,938 |

[a]Maintenance costs were discounted at 6 percent per annum.

## Modification Benefits from Water

The difference between quantity of water available from a modified lake and its unmodified equivalent per year is an estimate of the annual quantity of water produced by the modification. Estimates of the quantities of water available from both modified and unmodified lakes were based on lake filling dates of May 15 and September 15, and average seepage and evaporation rates for the study area (Appendix B, Table 1). Benefits estimates were based on the assumption that water caught in May would be stored until August 1; the most critical period of the irrigation season and water caught in September would be stored until March 31 for use as preplant irrigation water. June 15 was considered as an alternative irrigation date to August 1 for water caught on May 15 since by June 15, soil moisture from rains which produced the runoff caught on May 15 would likely be exhausted. The calculations of this study showed that during the typical year, water would be available from unmodified lakes on June 15, and that net new water produced by modifications on June 15 was less than net new water produced by modifications on August 1 of the typical year. The difference is explained by differences in the rate of evaporation from modified and unmodified lakes (lake volume curves are shown in Appendix B). This finding adds support to the idea that modifications should be used to store water for use in the critical period of the irrigation season since this practice contributes to alleviating the water shortage at that time of the irrigation season; i.e. in order to be effective at water storage, modifications need to be used for longer periods of time. This study shows that modifications would not be needed for water storage if the anticipated storage period is short; i.e, on the order of four weeks.

The estimated quantity of water saved per lake by each modification studied, is shown in Table 10. The minor modifications, sump and dyked lakes, were estimated to save zero water for August and March watering dates. The sump, Model I, and the dyked lake, Model II, are minimal modifications which could be used for lake water disposal purposes to reduce mosquito breeding in playas as opposed to being multipurpose modifications for water storage and lake-bed land protection. The major modifications were estimated to produce very little water from lakes smaller than 15 acres. Neither modification method studied was estimated

TABLE 10. Estimated Annual Quantity of Water Made Available per Lake per Modification for August 1, and March 31; Texas High Plains, 1967[a]

| Soil Area | Lake Size | Quantity of Water[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | August 31 | | | | March 31 | | | |
| | | Model I | Model II | Model III | Model IV | Model I | Model II | Model III | Model IV |
| | (acres) | (acre feet) | | | | | | | |
| Fine-Textured | 8 | 0 | 0 | 1.8 | 3.7 | 0 | 0 | 0.7 | 3.0 |
| | 15 | 0 | 0 | 5.4 | 8.7 | 0 | 0 | 2.3 | 6.9 |
| | 25 | 0 | 0 | 12.9 | 16.7 | 0 | 0 | 5.8 | 8.0 |
| | 45 | 0 | 0 | 34.1 | 37.8 | 0 | 0 | 14.2 | 11.0 |
| Medium-Textured | 8 | 0 | 0 | 0 | 2.9 | 0 | 0 | 0 | 0.5 |
| | 15 | 0 | 0 | 0 | 6.7 | 0 | 0 | 0 | 1.4 |
| | 25 | 0 | 0 | 0 | 8.7 | 0 | 0 | 0 | 2.4 |

[a]The following assumptions underlie the calculations:

1. Five out of six years lakes obtain an annual volume of water equal to one full lake volume, and one year out of six lakes obtain a greater than full lake volume.

2. Of the years lakes acquired one full volume, two-thirds of these years the volume would be acquired in May and one-third of these years the volume would be acquired in September.

3. Plants in the lake-bed cause evaporation to decrease, but in such cases transpiration increases by the same amount.

4. Seepage water losses of the lakes in the fine-textured soil area and the medium-textured soil area were a constant 15 percent and 60 percent of the total water loss, respectively (Hauser, 1966).

5. Water seepage loss per unit of water surface area is equal for modified and unmodified lakes.

[b]Model I = sump
Model II = dyked lake
Model III = circular reservoir
Model IV = rectangular pit

to save significant amounts of water in the medium-textured soils area for the August or March irrigation dates.

A comparison of the quantities of water in storage on August 1 and March 31 shows that the rectangular pit modification, Model IV, would be expected to yield more water benefits than other modifications considered, since this particular modification delivers more water on the selected dates than either of the other modifications studied. The circular reservoir would deliver some water in August and March, but the amount would be less than the amount delivered by the rectangular pit. It was estimated that the circular reservoir would produce a total of 156 thousand acre feet of playa water for irrigation use in the study area annually. The estimated rectangular pit production was 220 thousand acre feet annually.

The value of playa water stored to August 1, and March 31 is in the form of increased net farm income received by lake owners. Income estimates from playa water were based on cotton irrigation in the medium-textured soils area and grain sorghum irrigation in the fine-textured soils area. Previous studies of costs and returns to crops produced in the study area provided estimates of the expected average net income per acre foot of water used in irrigation.[13] Estimated net returns per acre foot of water used on cotton in the medium-textured soils area were $29.64, in 1966, for cotton irrigated with preplant plus three postplant waterings (21 acre inches). Estimated net returns per acre foot of water used in grain sorghum production in the fine-textured soils area were $31.92 for an irrigation level of preplant plus two postplant waterings (11.25 acre inches). Water benefits per lake, for the various modifications and lake sizes studied are shown in Table 11.

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[13] Grubb, H. W., Moore, D. S., and Lacewell, R. D., "Expected Production Requirements, Costs, and Returns for Major Agricultural Crops: Fine-Textured Soils--Texas High Plains," MP-848, Texas A & M University, College Station, Texas, September 1967. Osborn, James, Moore, Don, and Ethridge, Don, "Expected Production Requirements, Costs and Returns; Medium-Textured Soils, Texas High Plains," unpublished material, Department of Agricultural Economics, Texas Technological College, Lubbock, Texas, January 1967.

TABLE 11. Estimated Annual Quantity and Value of Water Saved Per Modification Per Lake; Texas High Plains[a]

| Soil Area | Lake Size | Circular Reservoir (Model III) | | Rectangular Pit (Model IV) | |
|---|---|---|---|---|---|
| | | Volume | Value | Volume | Value |
| | (acres) | (acre feet) | (dollars) | (acre feet) | (dollars) |
| Fine-Textured | 8 | 2.5 | 80 | 6.7 | 214 |
| | 15 | 7.7 | 246 | 15.6 | 498 |
| | 25 | 18.7 | 597 | 24.7 | 788 |
| | 45 | 48.3 | 1,542 | 49.4 | 1,577 |
| Medium-Textured | 8 | 0 | 0 | 3.4 | 101 |
| | 15 | 0 | 0 | 8.1 | 240 |
| | 25 | 0 | 0 | 11.1 | 329 |

[a]Since neither the sump nor the dyked lake yielded water on August 1 or March 31, the water benefits to those modifications would be zero.

[b]The annual volume of water saved was the sum of the volumes saved for August 1 and March 31.

[c]The net farm income to water was $31.92 per acre foot in the fine-textured soil area and $29.64 per acre foot in the medium-textured soil area.

## Modification Benefits from Lake-Bed Protection

In this study, land benefits from playa modification are the net incomes to flood protected lake-bed planted to dryland grain sorghum. The acreages protected by each modification studied and the net incomes per acre are presented below.

The dyked lake, Model II, the circular reservoir, Model III and the rectangular pit, Model IV, would be expected to protect lake-bed cropland from flooding. Model I the sump would not be expected to protect crops planted in lake-beds since water could not be removed rapidly enough ro prevent flood damage to crops. The dyked lake, Model II, would protect a smaller portion of the lake-bed from flooding than either the circular reservoir or the rectangular pit since the dyke design permits spilling into adjacent lake sections when more than one-fourth of a full lake volume is accumulated (Appendix A). Model II would provide no protection in instances where a full lake volume of runoff were present (Table 12).

TABLE 12. Estimated Annual Acreage Protected from Flooding and Annual Net Income Per Lake for Alternative Modification Methods; Texas High Plains, 1966[a]

| Soil Area | Lake Size | Dyked Lake (Model II) | | Circular Reservoir (Model III) | | Rectangular Pit (Model IV) | |
|---|---|---|---|---|---|---|---|
| | | Acreage per Lake | Value per Lake | Acreage per Lake | Value per Lake | Acreage per Lake | Value per Lake |
| | (acres) | (acres) | (dollars) | (acres) | (dollars) | (acres) | (dollars) |
| Fine-Textured | 8 | 1.68 | 18 | 5.13 | 54 | 5.87 | 62 |
| | 15 | 2.43 | 25 | 9.50 | 100 | 11.00 | 116 |
| | 25 | 3.90 | 42 | 15.83 | 167 | 18.33 | 193 |
| | 45 | 4.37 | 46 | 28.50 | 300 | 33.00 | 348 |
| Medium-Textured | 8 | 1.23 | 13 | 5.13 | 55 | 5.87 | 63 |
| | 15 | 2.40 | 26 | 9.50 | 102 | 11.00 | 119 |
| | 25 | 4.50 | 47 | 15.83 | 171 | 18.33 | 198 |

[a]Model I had zero returns to land

[b]Assuming the following:

1. Five out of six years the lake obtained an annual volume of water equal to one full volume and one year out of six the lakes obtained a greater than full volume of water.
2. An annual rainfall of more than 25 inches resulted in a volume greater than the full lake volume.

[c]Net income from protected lake-bed land was estimated at $10.54 per acre in the fine-textured soils area and $10.81 per acre in the medium-textured soils area.

Modifications Models III and IV, the circular reservoir and rectangular pit, would be expected to protect 80 and 90 percent respectively of lake-bed land for all years except when total accumulation exceeds one full-lake volume of the unmodified lake. These designs were evaluated for modifications constructed to contain a maximum of one full lake volume. When a greater than full-lake volume is accumulated, the lake-bed would flood. This is expected to happen each time annual precipitation exceeds 25 inches. Study area precipitation records for the past 55 years indicate that annual precipitation exceeds 25 inches one year in six, thus no land benefits to modifications were claimed for one sixth of the number of years of expected modification life. Average annual benefits were adjusted downward to account for the expected crop losses due to modification flooding.

Estimates of the quantity of lake-bed land protected per representative lake are shown in Table 12. The representative lake estimates, when applied to the respective number of lakes in each size category, provide estimates of the quantity of lake-bed land protected in the study area. The dyked lake was estimated to protect 33 thousand (24 thousand in the fine-textured soils area and nine thousand in the medium-textured soils area) acres of lake-bed land from flooding annually.

The circular reservoir was estimated to protect 152 thousand acres of lake-bed land annually (177 thousand acres in the fine-textured soils area and 35 thousand acres in the medium-textured soils area). Estimated lake-bed protection by the rectangular pit was 176 thousand acres annually (135 thousand acres in the fine-textured soils area and 41 thousand acres in the medium-textured soils area).

Net income per acre of dryland grain sorghum was estimated at $10.81 in the medium-textured soils area and $10.54 in the fine-textured soils area.[14] The income estimates were applied to the calculated annual number of lake-bed acres protected by playa modification for the purpose of estimating study area annual flood protection benefits from each modification method studied. The rectangular pit method of modification,

[14] Ibid. Page

Model IV, yielded higher gross lake-bed protection benefits estimates than other modification methods studied. The Model IV modification concentrates playa water into a modified lake of smaller surface size than either of the other modification methods considered, thus this method makes more lake-bed acres available for crop production per lake.

## Net Benefits to Playa Modification

Alternative playa modification methods were compared on the basis of present worth of net farm income from water storage and lake-bed land protection. Annual modification benefits estimates were expressed as the sum of annual water and lake-bed land net farm incomes minus annual modification maintenance costs. Annual benefits net of modification maintenance costs, when discounted to present value, are estimates of the present value of modifications (Appendix A). If playa modification construction cost at present, exceeds present worth of future annual benefits as future annual benefits are expressed above, then playa modification would not be economically feasible. Benefits estimates were calculated for each modification model applied to each representative lake considered in the study, for the purpose of gaining information about modification feasibility for different sizes of lakes within the study area (Table 13).

TABLE 13.--Estimated Annual Modification Land and Water Benefits per Lake; Texas High Plains, 1966[a]

| Soil Area | Lake Size | Sump (Model I) | Dyked Lake (Model II) | Circular Reservoir (Model III) | Rectangular Pit (Model IV) |
|---|---|---|---|---|---|
| | (acres) | | | (dollars) | |
| Fine-Textured | 8 | NA | -4 | 66 | 136 |
| | 15 | NA | -6 | 238 | 281 |
| | 25 | NA | -15 | 586 | 318 |
| | 45 | NA | -56 | 1,530 | 495 |
| Medium-Textured | 8 | NA | -7 | -2 | 45 |
| | 15 | NA | -4 | 8 | 102 |
| | 25 | NA | -4 | 77 | 44 |

[a]Annual land and water benefits per lake minus annual lake maintenance cost.
NA = not applicable; zero land and water benefits.

Both the circular reservoir, Model III, and the rectangular pit, Model IV, yielded positive annual benefits estimates for all lake sizes except the eight acre lake of the medium-textured soils area. The dyked lake had greater annual maintenance costs than annual water and lake-bed land benefits (Table 13).

Total study area annual benefits were estimated by expanding the representative lake benefits discussed above by the number of lakes in each size category. The annual benefits expressed in this way are estimates of annual incomes from investments in playa modification, since other costs, including annual modification maintenance costs have been deleted (Table 14). Present worth of these future annual incomes were calculated at alternative discount rates for the purpose of determining economic feasibility and rate of return to playa modification investments.

According to estimates of this study, construction costs of the Model IV modification exceeded the present worth of future annual benefits for both a 20 year and a 40 year benefit stream, therefore, Model IV, would not be a feasible modification method in the study area. Net benefits to Model III, the circular reservoir discounted at 6 percent annual discount rate were positive for 15, 25, and 45 acre lakes in the fine-textured soils area but were negative in the medium-textured soils area; i.e. present worth of the annual benefits stream (Table 13) minus construction costs (Table 7) were positive for these lake sizes, when the benefits were discounted at 6 percent per annum (Table 15). At a 12 percent discount rate, the estimated modification net benefits to the 15 acre lake in the fine-textured soils area is negative at both 20 and 40 year project lives. (Table 15).

Under the assumptions of this study, estimated modification net benefits from playa water and land resources development in the medium-textured soil area were negative for all lake sizes and modification methods studied. A major reason for this was the high seepage rate of water in the playas of the medium-textured soils area-- a factor which reduces opportunity for playa modification to function either at water

TABLE 14.--Estimated Annual Land and Water Benefits from Modification of the Texas High Plains Playas; 1966[a]

| Soil Area | Lake Size | Number of Lakes | Sump (Model I) | Dyked Lake (Model II) | Circular Reservoir (Model III) | Rectangular Pit (Model IV) |
|---|---|---|---|---|---|---|
| | (acres) | | | (dollars) | | |
| Fine-Textured | 0-5 | 2,170 | NA | NA | NA | NA |
| | 5-10 | 1,839 | NA | -7,356 | 121,374 | 250,104 |
| | 10-20 | 2,417 | NA | -14,502 | 575,246 | 679,177 |
| | 20-30 | 1,241 | NA | -18,615 | 727,226 | 394,638 |
| | 30+ | 2,272 | NA | -127,232 | 3,476,160 | 1,124,640 |
| Total | | 9,939 | NA | -167,705 | 4,900,006 | 2,448,559 |
| Medium-Textured | 0-5 | 2,629 | NA | NA | NA | NA |
| | 5-10 | 1,877 | NA | -13,139 | -3,754 | 84,465 |
| | 10-20 | 1,702 | NA | -6,808 | 13,616 | 173,604 |
| | 20+ | 587 | NA | -2,348 | 45,199 | 25,828 |
| Total | | 6,795 | NA | -22,295 | 55,061 | 283,897 |
| TOTAL | | 16,734 | NA | -190,000 | 4,955,067 | 2,732,456 |

[a](annual land and water benefits minus annual lake maintenance cost) x (number of lakes);

NA = not applicable.

TABLE 15.--Estimated Modification Net Benefits (in dollars) per Representative Lake at Alternative Discount Rates for 20 and 40 Year Benefit Streams, Texas High Plains, 1966.[a]

| Soil Area | Lake Size in Acres | Discount Rate: 0 Percent Model I | 0 Percent Model II | 0 Percent Model III | 0 Percent Model IV | 6 Percent Model I | 6 Percent Model II | 6 Percent Model III | 6 Percent Model IV | 12 Percent Model I | 12 Percent Model II | 12 Percent Model III | 12 Percent Model IV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (20 year benefit stream) | | | | | | | | | | | | | |
| Fine-Textured | 8 | -25 | -528 | -49 | -75 | -25 | -494 | -612 | -1,235 | -25 | -478 | -880 | -1,787 |
| | 15 | -25 | -747 | 2,599 | -1,046 | -25 | -696 | 569 | -3,443 | -25 | -672 | -397 | -4,584 |
| | 25 | -30 | -1,436 | 8,165 | -6,904 | -30 | -1,308 | 3,166 | -9,617 | -30 | -1,248 | 787 | -10,908 |
| | 45 | -50 | -3,174 | 24,691 | -18,691 | -50 | -2,696 | 11,307 | -22,913 | -50 | -2,472 | 5,095 | -24,923 |
| Medium-Textured | 8 | -25 | -570 | -1,174 | -1,480 | -25 | -510 | -1,157 | -1,864 | -25 | -482 | -1,149 | -2,080 |
| | 15 | -25 | -678 | -1,712 | -3,091 | -25 | -644 | -1,780 | -3,961 | -25 | -628 | -1,813 | -4,375 |
| | 25 | -30 | -1,126 | -1,284 | -8,777 | -30 | -1,092 | -1,941 | -9,152 | -30 | -1,091 | -2,253 | -9,331 |
| (40 year benefit stream) | | | | | | | | | | | | | |
| Fine-Textured | 8 | -25 | -608 | 1,271 | 2,645 | -25 | -508 | -376 | -749 | -25 | -481 | -830 | -1,683 |
| | 15 | -25 | -867 | 7,359 | 4,574 | -25 | -717 | 1,420 | -2,438 | -25 | -676 | -217 | -4,369 |
| | 25 | -30 | -1,736 | 19,885 | -544 | -30 | -1,361 | 5,262 | -8,479 | -30 | -1,268 | -1,234 | -10,665 |
| | 45 | -50 | -4,294 | 54,958 | -8,791 | -50 | -2,896 | 16,779 | -21,143 | -50 | -2,515 | 6,263 | -24,545 |
| Medium-Textured | 8 | -25 | -710 | -1,214 | -580 | -25 | -535 | -1,164 | -1,703 | -25 | -488 | -1,150 | -2,012 |
| | 15 | -25 | -758 | -1,552 | -1,051 | -25 | -658 | -1,752 | -3,596 | -25 | -631 | -1,807 | -4,297 |
| | 25 | -30 | -1,206 | 216 | -7,897 | -30 | -1,106 | -1,705 | -8,996 | -30 | -1,079 | -2,235 | -9,927 |

[a] $\left[\frac{\text{Annual Water plus Lake-Bed Land Benefits - Annual Maintenance Cost}}{r}\right]\left[1 - (1 + r)^{-n}\right]$ — Construction Cost

where r = 0, 6, and 12 percent
n = 20 and n = 40
annual maintenance cost = five percent of construction cost

Model I = sump
Model II = dyked lake
Model III = circular reservoir
Model IV = rectangular pit

storage or lake-bed land protection.

Estimates for the fine-textured soils area showed that modification of the smaller playas (less than 10 acres) would not produce enough water and land benefits to justify the construction expenditures. The factor of small quantities of both water and land per lake, in relation to modification costs, are the underlying reasons for negative modification benefit estimates from small lakes. Alternative methods of dealing with the smaller lakes would be lake filling to eliminate water accumulations, the connection of a group of small playas into one large playa, or drainage of small playas into near-by larger playas. These alternatives were not evaluated in this study.

Estimated study area net water and land benefits from modification of playas using the circular reservoir, Model III, are shown in Table 16. The net benefits of this study are estimates of the excess benefit above modification construction and maintenance costs; i.e. net benefits estimates of Table 16 are either positive or negative residuals after modification construction and future annual maintenance costs have been deleted from estimated gross benefits. For example a positive net benefit, such as the $1.375 million for the 2,417 lakes in the 10-19.99 size category of the fine-textured soils area; the 20 year benefit stream calculated at 6 percent discount rate, indicates that for a 20 year time period, modification of these lakes would return 6 percent per annum on modification investment and leave a residual of $1.375 million. In reality, modification of the 10-19.99 acre lakes of the fine-textured soils area was estimated to return more than 6 percent to investment; i.e. the net benefit was greater than zero. The actual rate of return to investment is the discount rate at which present worth of net benefits, as net benefits are defined in this study, is zero. Estimated present worth of net benefits for the 2,417 lakes of the example above was a negative $0.980 million at a 12 percent discount rate. On the basis of these estimates, estimated rate of return to modification of 10-19.99 acre lakes of the fine-textured soils area is between 6 and 12 percent for a 20 year modification life expectancy. The other lake size categories of Table 16 can be intrepreted analogously to that applied in the example above.

TABLE 16.--Estimated Total Study Area Net Benefits of 20 Year and 40 Year Benefit Streams from Modification Model III, Circular Reservoir--Texas High Plains; 1966.[a]

| Soil Area | Lake Size | Number of Lakes | 20 Year Benefit Stream Discount Rate | | | 40 Year Benefit Stream Discount Rate | | |
|---|---|---|---|---|---|---|---|---|
| | | (acres) | 0% | 6% | 12% | 0% | 6% | 12% |
| Fine-Textured | 0-4.99[d] | 2,170 | -2,560 | -1,962 | -1,758 | -3,840 | -2,242 | -1,807 |
| | 5-9.99 | 1,839 | -90 | -1,125 | -1,618 | 2,337 | -691 | -1,526 |
| | 10-19.99 | 2,417 | 6,282 | 1,375 | -980 | 17,787 | 3,342 | -524 |
| | 20-29.99 | 1,241 | 10,133 | 3,929 | 977 | 24,677 | 6,530 | 1,531 |
| | over 30 | 2,272 | 55,341 | 25,690 | 11,576 | 124,865 | 38,123 | 14,230 |
| Total | | 9,939 | 69,106 | 27,906 | 8,217 | 165,826 | 45,062 | 11,904 |
| Medium-Textured | 0-4.99[d] | 2,629 | -4,898 | -2,434 | -2,126 | -4,631 | -2,709 | -2,185 |
| | 5-9.99 | 1,877 | -2,804 | -2,172 | -2,157 | -2,278 | -2,178 | -916 |
| | 10-19.99 | 1,702 | -2,914 | -3,030 | -3,086 | -2,641 | -2,982 | -3,076 |
| | 20-29.99 | 587 | -492 | -743 | -863 | 83 | -653 | -856 |
| Total | | 6,795 | -10,507 | -8,379 | -8,231 | -9,467 | -8,528 | -7,033 |
| TOTAL | | 16,734 | 58,599 | 19,527 | -14 | 156,359 | 36,534 | 4,871 |

[a]Computed by multiplying the number of lakes in each size category by the annual net benefit per lake (Tables 1, 2, 3 and 15.)

[b]Model III was used because this model had highest net benefits of models studied.

[c]NA = not applicable

[d]Rectangular pit, Model IV, was used for modifying 0-4.99 acre lakes since Model III is inapplicable to lakes in this size range.

The analyses of this study show that approximately 5,930 lakes (35.4 percent of total study area lakes) could be profitably modified on the basis of water and land benefits. The water and land net benefits to these 5,930 lakes were estimated at a present worth of approximately $31 million (6 percent discount rate) for a 20 year life modification and approximately $48 million if the modifications were to last 40 years. According to estimates of this study, modifications of lakes over 10 acres in size in the fine-textured soils area would return more than six percent on investment. Modification of lakes over 20 acres in size would return more than 12 percent on investment (Table 16). The 5,930 lakes for which net benefits estimates were positive at a 6 percent discount rate would produce an estimated 151 thousand acre feet of water annually for irrigation use in the study area. These same lakes would be expected to protect approximately 107 thousand acres of lake-bed cropland from flooding annually.

There are additional benefits to playa modification in the form of health benefits from control of Culex tarsalis, an encephalitis spreading mosquito.[15] Estimated present worth (calculated at 6 percent discount rate) of future health benefits for 20 year playa modification were $1.12 million in the fine-textured soils area and $0.56 million in the medium-textured soils area. The benefits of 40 year modifications, if modifications last that long, were estimated at $1.47 and $0.74 million respectively for the fine-and medium-textured soils areas. The analysis shows, however, that playa modification would not be economically feasible in the medium-textured soils area on the basis of combined water, lake-bed land and health benefits, and that the added health benefits in the fine-textured soils area would not be sufficient to justify modifying lakes under 10 acres in surface size.

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[15] Grubb, H. W., Parks, D. L., and Sciple, G. W., "Benefits and Costs of Modifying Playas to Reduce Encephalitis in the Texas High Plains," Department of Agricultural Economics, Texas Technological College, Lubbock, Texas, February 1968.

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# APPENDIX A
# METHODOLOGY

Appendix A

METHODOLOGY

The genralized procedure of identifying (1) the physical characteristics of playa lakes and the associate lake resources, (2) the cost of making more of these resources available by lake modification, and (3) the private benefits from lake modification is presented below.

## Physical Characteristics of Playa Lakes

### Enumerating and Classifying Playa Lakes

The lakes were defined as being that area of land covered by a Randall Series Soil and enclosed by a lake-bed perimeter contour line. The lakes of each county were simultaneously counted and classified according to surface size from soil and topographic maps of the Soil Conservation Service and the United States Geological Survey. The lakes were classified on the basis of eight size categories. These size categories were on five acre intervals from zero to 20 acres, 10 acre intervals from 20 to 50 acres, and one interval of 50 acres or more. For counties which had not been completely mapped by the Soil Conservation Service or the United States Geological Survey, the percentage of the mapped area to the total county area was calculated; this percentage was used to project the lake counts of the mapped county area to the total county area.

### Estimating Volume of Playa Lakes

Information was obtained on the shape of various size playas in the fine-and the medium-textured soil area of the Texas High Plains for the purpose of estimating the volume of playa lakes. Obtaining lake shape information involved (1) analyzing data on lakes in the area that had been topographically mapped and (2) constructing representative topographic maps of lakes in areas which had not been mapped.

Cronin's data for the fine-textured soil area of an 1800 square mile portion of Castro, Swisher, Lamb, and Hale Counties gave area, depth and volume relationships for 62 sample lakes.[1] Depth and volume

[1]Cronin, J. G., "A Summary of the Occurrence and Development of Groundwater in the Southern High Plains," Texas Board of Water Engineers, Bulletin No. 6107, Austin, Texas, 1961.

data in other subareas of the High Plains were obtained by sampling lakes in each subarea. The topographically mapped portions of the North, Central, and South areas were divided into seven and one-half by nine mile rectangles. A random sample of rectangles of size 10 was drawn from each of the North, Central and South Areas. Eighteen lakes were drawn from each of these ten rectangle samples. Topographic maps were constructed and the lake volumes were computed for the sample lakes. The volume of individual lakes was fixed at that quantity of water contained when water levels were at the lake-bed perimeter contour. The volume of a lake was computed from the area contained within contour lines and contour elevation. The following formula was used to calculate lake volume:

$$V = \sum_{i=o}^{n-1} V_i \qquad (i = 0,1,2, \ldots n-1)$$

where V is volume in cubic feet and

$$V_i = \left[\frac{h_{i,\,i+1}}{3}\right] \left[a_i + a_{i+1} (a_i\, a_{i+1})^{\frac{1}{2}}\right]$$

$V_i$ is volume, in cubic feet, between contour lines i and i+1,

$h_{i,\,i+1}$ is vertical distance, in feet, between contour lines i and i+1

$a_i$ is surface area, in square feet, encompassed by contour line i,

$a_{i+1}$ is surface area, in square feet, encompassed by contour line i+1,

Volume in acre feet is obtained by dividing V above by 43,560.

Data obtained from 18 sample lakes in the South area and 80 sample lakes in the North and Central areas were used to estimate the relationship between lake surface size and lake volume for various size lakes for each of the South and North-Central subareas, The total lake storage volume of each subarea was estimated by using the lake number and lake volumes estimates obtained through procedures outlined above.

## Modification Costs

There are a large number of possible combinations of modification types and sizes for various sized lakes. Four practicable modification

models were chosen for four representative lake sizes (8, 15, 25 and 45 acre lakes). The four modification models were as follows:

Model I = sump

Model II = divided lake

Model III = circular reservoir

Model IV = rectangular pit

The modification construction costs were expressed as follows:

$$C_m = (X_{m1} + X_{m2}) X_{m3} \quad , (m=1, \ldots, 4)$$

where

$C_m$ is construction costs of modification m,

$X_{m1}$ is number of cubic yards of soil moved for excavation of modification m,

$X_{m2}$ is number of cubic yards of soil moved for water diversion into modification m,

$X_{m3}$ is price per cubic yard of soil moved for construction of modification m.

The annual maintenance cost of each modification model was estimated at five percent of the original cost.[2] Because the maintenance costs would be incurred annually in the future, they were considered as annual negative benefits and were added algebraically to estimated annual gross benefits to modification.

## Annual Benefits

The annual benefits to modification included the net value of water saved annually plus net return to land protected annually. Annual net benefits, B were stated as follows:

$$B = (Q_w P_w) + (Q_1 P_1)$$

where

$Q_w$ is quantity of water saved, in acre feet per year

[2] Dvoracek, M. J., unpublished data. Department of Agricultural Engineering, Texas Technological College, Lubbock, Texas, 1967.

$P_w$ is net irrigation return per acre foot of water saved,
$Q_1$ is quantity of the land protected from flooding, in acres per year,
$P_1$ is the increase in net revenue per acre of land protected by modification.

The quantity of water stored over time in modified lakes was compared with the quantity of water stored over time in unmodified lakes for the purpose of estimating the quantity of water made available through modification of lakes. The volumes of the modifications and of the unmodified lakes were expressed as a function of depth. The Model III and IV modification volume-depth relationships were expressed mathematically. However, for modification Models I and II and for the unmodified lake, expressing volume as a function of depth required identifying the shape of the lake bottom Volume-depth data for various elevations below the lake-bed contours were obtained from sample lakes for each of the four lake sizes studied.[3]

The water storage capacity of modified and unmodified lakes were estimated from (1) the volume-depth relationships for the modifications and the corresponding unmodified lakes, and (2) the change in depth with time.

Volume-depth estimating formuals of unmodified lakes and the modifications were used to estimate the quantity of water saved by the modifications. The compute volume-depth relationships for specific sizes of unmodified lakes considered in this study are as follows:

A. Fine textured soil area

$\log_e V_1 = 0.777185 + 1.773856 \log_e d_1$ (8 acre lake; $d_1 = 1.84$ feet)

$\log_e V_2 = 1.833828 + 1.573133 \log_e d_2$ (15 acre lake; $d_2 = 1.74$ feet)

$\log_e V_3 = 1.812300 + 1.843195 \log_e d_3$ (25 acre lake; $d_3 = 2.37$ feet)

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[3]Because there were so few large lakes in the medium-textured soil area (south area), the 45 acre lake was not considered for modification. The following regression equations was fitted. $\log_e V = A + b \log_e d$, where V is volume in acre-feet, d is depth in feet, and A and B are constants for each soil area.

$\log_e V_4 = 1.982267 + 1.931779 \log_e d_4$ (45 acre lake; $d_4 = 3.09$ feet)

B. Medium-textured soil area

$\log_e V_5 = 0.830145 + 1.906693 \log_e d_5$ (8 acre lake; $d_5 = 1.57$ feet)

$\log_e V_6 = 1.875156 + 1.635222 \log_e d_6$ ( 15 acre lake; $d_6 = 2.36$ feet)

$\log_e V_7 = 2.175555 + 1.809436 \log_e d_7$ (25 acre lake; $d_7 = 3.28$ feet)

where $V_i$ is volume in acre-feet and $d_i$ is lake depth in feet. The above functions were solved for lake depth, using the previously determined volumes (V) of full lakes for each each of the lake sizes studied (Figure 2), for the purpose of calculating estimates of the daily rate of disappearance of lake water under both modified and unmodified conditions. The calculated lake water loss by seepage and by evaporation per unit surface area were combined to estimate the change in lake depth per day. Water in storage (V) in unmodified and modified lakes was expressed as a function of time (days), and was calculated on a daily basis beginning with the estimated date of lake filling (Appendix B).

The annual net return per acre-foot of water saved by modification ($P_w$) was that return per acre-foot of water used for irrigation.

Regression analysis of the data expressed volume as a function of land area, and indicated the land area of the unmodified lakes covered by various volumes of water by comparing the unmodified lake surface with the modified lake surface area for a particular volume. The number of acres protected from flooding ($Q_1$) were determined for Models II, III and IV. The annual net returns per acre of the lake land reclaimed by modification was considered as land protection benefits since unmodified lake-beds were subject to flooding and consequently had expected annual net revenues of zero.

Present Value of Future Dollars

Benefits and costs to be incurred in the future were discounted to give present dollar values for modification model evaluation. Present worth of net benefits to modification was calculated as follows:

$$PW\ (B) = \sum_{i=1}^{n} B_i - C_m$$

where $B_i$ is net benefit in year i and $C_m$ is present modification construction cost.

# APPENDIX B

# WATER STORAGE CURVES

# FOR

# MODIFIED AND UNMODIFIED PLAYA LAKES

Appendix B

TABLE 1.--Estimated Monthly Water Losses From Playa Lakes; Texas High Plains.

| Soil Area | Month | Seepage Loss by Months[a] ac. in/day/acre | Playa Lake Surface Evaporation Loss by Months[d] ac. in/day/acre | Total Loss by Months ac. in/day/acre | Total Loss by Months ac.ft./day/acre |
|---|---|---|---|---|---|
| Fine-Textured | Jan. | .036[e] | .062[c] | .098[d] | .0082 |
| | Feb. | .036 | .100 | .136 | .0113 |
| | Mar. | .036 | .178 | .214 | .0178 |
| | Apr. | .036 | .247 | .283 | .0236 |
| | May | .036 | .277 | .313 | .0261 |
| | June | .036 | .338 | .374 | .0312 |
| | July | .036 | .342 | .378 | .0315 |
| | Aug. | .036 | .310 | .346 | .0288 |
| | Sept. | .036 | .261 | .297 | .0247 |
| | Oct. | .036 | .191 | .227 | .0189 |
| | Nov. | .036 | .118 | .154 | .0128 |
| | Dec. | .036 | .078 | .114 | .0095 |
| Medium-Textured | Jan. | .310 | .062 | .372 | .0310 |
| | Feb. | .310 | .100 | .410 | .0342 |
| | Mar. | .310 | .178 | .488 | .0407 |
| | Apr. | .310 | .247 | .557 | .0464 |
| | May | .310 | .277 | .587 | .0489 |
| | June | .310 | .338 | .648 | .0540 |
| | July | .310 | .342 | .652 | .0543 |
| | Aug. | .310 | .310 | .620 | .0517 |
| | Sept. | .310 | .261 | .571 | .0476 |
| | Oct. | .310 | .191 | .501 | .0417 |
| | Nov. | .310 | .118 | .428 | .0323 |

[a]Seepage loss per day = (annual evaporation loss) / (per cent of total loss that was evaporation) (365)

[b]"Hydrology, Conservation and Management of Runoff Water in Playa on the Southern High Plains," Conservation Report No. 8, Agricultural Research Service, U.S.D.A., Washington, D. C., Aug. 1966, p. 12.

[c]Monthly loss divided by number of days in month

[d]Total loss = evaporation loss plus seepage loss

[e]Seepage loss where seepage and evaporation percent of total loss is 15 and 85 respectively

[f]Seepage loss where seepage and evaporation percent of total loss is 60 and 40 respectively.

Appendix B

TABLE 2.--Estimated Present Value (in dollars) of 20 and 40 Year Water Benefits Streams Per Lake For Various Modification Models at Alternative Discount Rates; Texas High Plains, 1965-1966.*

| Soil Area | Lake Size in Acres | Discount Rate | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Percent | | | | 6 Percent | | | | 12 Percent | | | |
| | | Model I | Model II | Model III | Model IV | Model I | Model II | Model III | Model IV | Model I | Model II | Model III | Model IV |
| | | (20 year benefit stream) | | | | | | | | | | | |
| Fine-Textured | 8 | 0 | 0 | 1,600 | 4,280 | 0 | 0 | 918 | 2,455 | 0 | 0 | 593 | 1,586 |
| | 15 | 0 | 0 | 4,920 | 9,960 | 0 | 0 | 2,822 | 5,712 | 0 | 0 | 1,823 | 3,690 |
| | 25 | 0 | 0 | 11,940 | 15,760 | 0 | 0 | 6,848 | 9,038 | 0 | 0 | 4,424 | 5,839 |
| | 45 | 1,660 | 440 | 30,840 | 31,540 | 952 | 252 | 17,687 | 18,088 | 615 | 163 | 11,426 | 11,686 |
| Medium-Textured | 8 | 0 | 0 | 0 | 2,020 | 0 | 0 | 0 | 1,158 | 0 | 0 | 0 | 748 |
| | 15 | 0 | 0 | 0 | 4,800 | 0 | 0 | 0 | 2,753 | 0 | 0 | 0 | 1,778 |
| | 25 | 0 | 0 | 940 | 6,580 | 0 | 0 | 539 | 3,774 | 0 | 0 | 348 | 2,438 |
| | | (40 year benefit stream) | | | | | | | | | | | |
| Fine-Textured | 8 | 0 | 0 | 3,200 | 8,560 | 0 | 0 | 1,204 | 3,220 | 0 | 0 | 654 | 1,749 |
| | 15 | 0 | 0 | 9,840 | 19,920 | 0 | 0 | 3,701 | 7,493 | 0 | 0 | 2,011 | 4,070 |
| | 25 | 0 | 0 | 23,880 | 31,520 | 0 | 0 | 8,983 | 11,856 | 0 | 0 | 4,879 | 6,440 |
| | 45 | 3,320 | 880 | 61,680 | 63,080 | 1,249 | 331 | 23,201 | 23,728 | 678 | 180 | 12,603 | 12,889 |
| Medium-Textured | 8 | 0 | 0 | 0 | 4,040 | 0 | 0 | 0 | 1,520 | 0 | 0 | 0 | 825 |
| | 15 | 0 | 0 | 0 | 9,600 | 0 | 0 | 0 | 3,611 | 0 | 0 | 0 | 1,962 |
| | 25 | 0 | 0 | 1,880 | 13,160 | 0 | 0 | 707 | 4,950 | 0 | 0 | 384 | 2,689 |

*$\frac{[\text{Annual Water Benefit}]\ [1 - (1 + r)^{-n}]}{r}$

where r = zero, six and 12 percent
n = 20, and n = 40

Model I = small sump
Model II = divided lake
Model III = reservoir
Model IV = pit

Appendix B

TABLE 3.--Estimated Present Value (in Dollars) of 20 and 40 Year Land Benefits Stream Per Lake for Various Modification Models at Alternative Discount Rates: Texas High Plains, 1965-1966.*

| Soil Area | Lake Size in Acres | Discount Rate | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Percent | | | 6 Percent | | | 12 Percent | | |
| | | Model II | Model III | Model IV | Model II | Model III | Model IV | Model II | Model III | Model IV |
| | | (20 year benefit stream) | | | | | | | | |
| Fine-Textured | 8 | 360 | 1,080 | 1,240 | 206 | 619 | 711 | 133 | 400 | 459 |
| | 15 | 720 | 2,000 | 2,320 | 413 | 1,147 | 1,331 | 267 | 741 | 860 |
| | 25 | 1,040 | 3,340 | 3,860 | 596 | 1,915 | 2,214 | 385 | 1,237 | 1,430 |
| | 45 | 920 | 6,000 | 6,960 | 528 | 3,441 | 3,992 | 341 | 2,223 | 2,579 |
| Medium-Textured | 8 | 260 | 1,100 | 1,260 | 149 | 631 | 723 | 96 | 408 | 467 |
| | 15 | 520 | 2,040 | 2,380 | 298 | 1,170 | 1,365 | 193 | 756 | 882 |
| | 25 | 940 | 3,420 | 3,960 | 539 | 1,961 | 2,271 | 348 | 1,267 | 1,467 |
| | | (40 year benefit stream) | | | | | | | | |
| Fine-Textured | 8 | 720 | 2,160 | 2,480 | 271 | 813 | 933 | 147 | 441 | 507 |
| | 15 | 1,440 | 4,000 | 4,640 | 542 | 1,505 | 1,745 | 294 | 817 | 948 |
| | 25 | 2,080 | 6,680 | 7,720 | 782 | 2,513 | 2,904 | 425 | 1,365 | 1,577 |
| | 45 | 1,840 | 12,000 | 13,920 | 692 | 4,514 | 5,236 | 376 | 2,452 | 2,844 |
| Medium-Textured | 8 | 520 | 2,200 | 2,520 | 196 | 828 | 948 | 106 | 450 | 515 |
| | 15 | 1,040 | 4,080 | 4,760 | 391 | 1,535 | 1,791 | 212 | 834 | 973 |
| | 25 | 1,880 | 6,840 | 7,920 | 707 | 2,573 | 2,979 | 384 | 1,398 | 1,618 |

* $\frac{[\text{Annual Land Benefits}]\,[1 - (1 + r)^{-n}]}{r}$

where r = zero, six and twelve percent
n = 20 and n = 40

Model I = modification recovered no land
Model II = divided land
Model III = reservoir
Model IV = pit

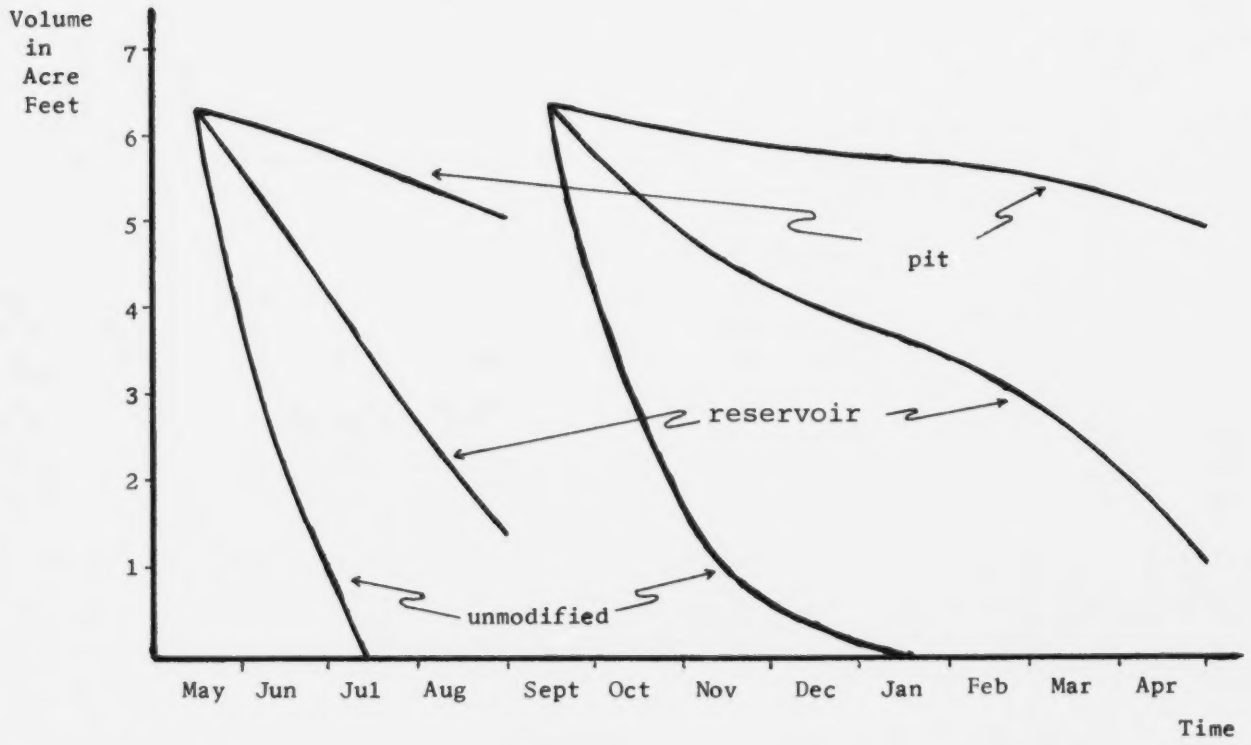


Figure 1 : Volume Over Time of 8 Acre Lake with Filling Dates of May 15 and September 15 -- Fine-Textured Soil Area.

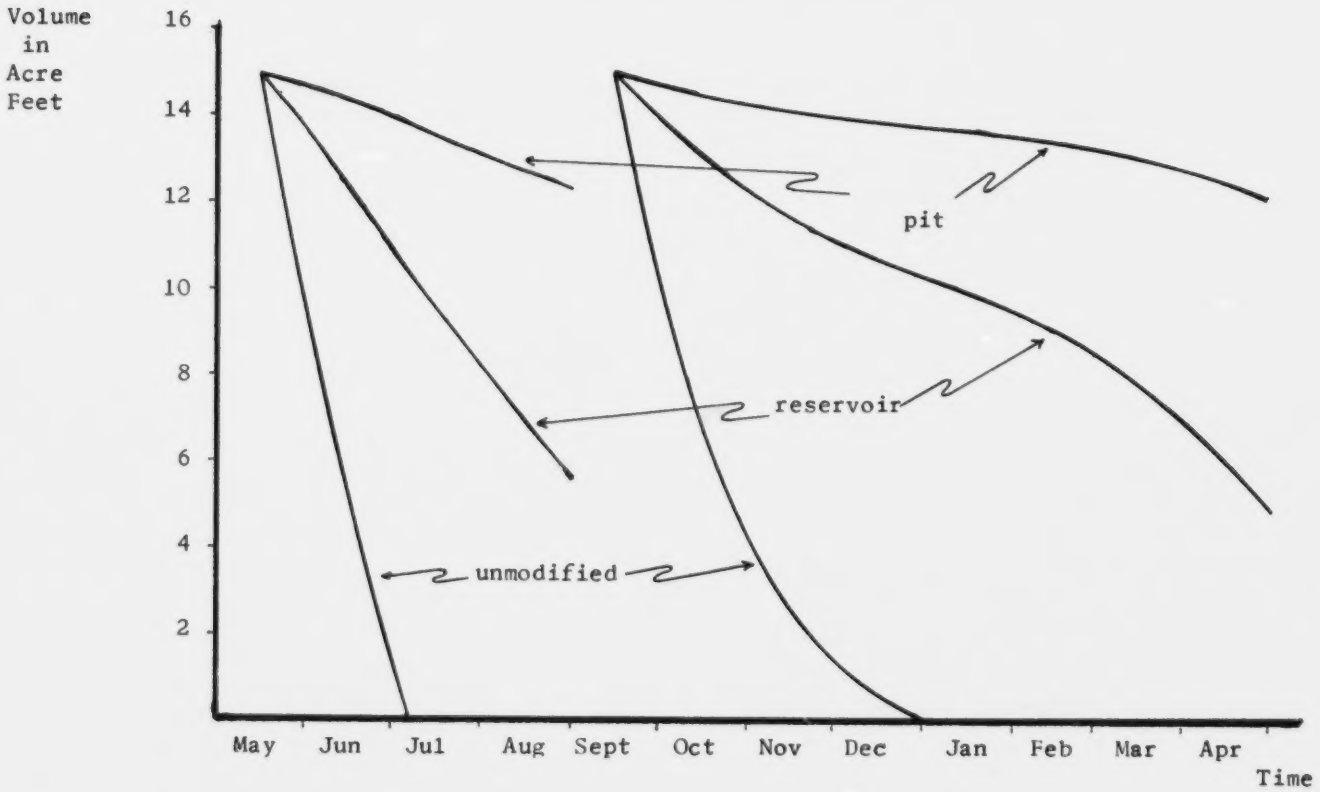


Figure 2 : Volume Over Time of 15 Acre Lake with Filling Dates or May 15 and Sept. 15 -- Fine-Textured Soil Area.

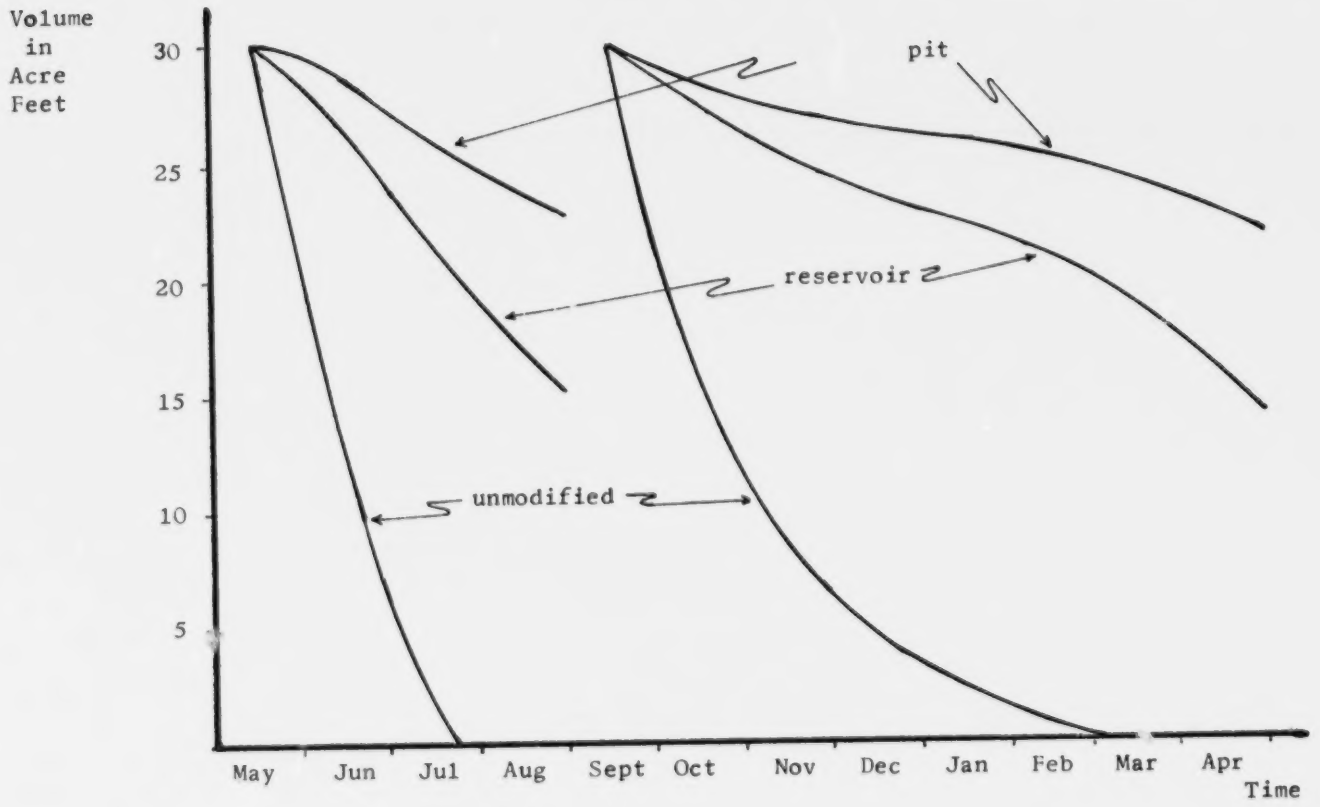


Figure 3: Volume Over Time of 25 Acre Lake with Filling Dates of May 15 and Sept. 15 -- Fine-Textured Soil Area.

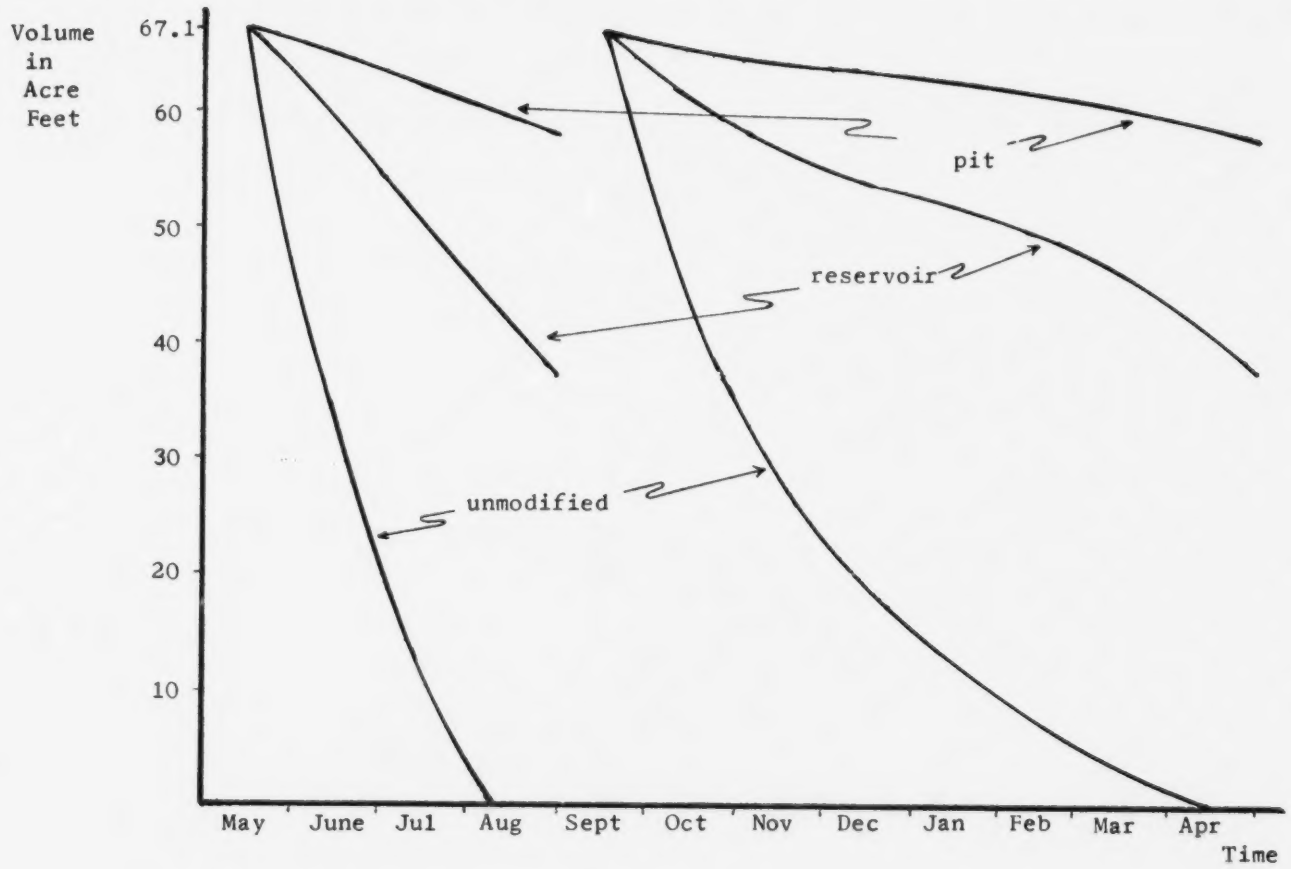


Figure 4: Volume of Water Over Time of 45 Acre Lake with Filling Dates of May 15 and Sept. 15 -- Fine-Textured Soil Area.

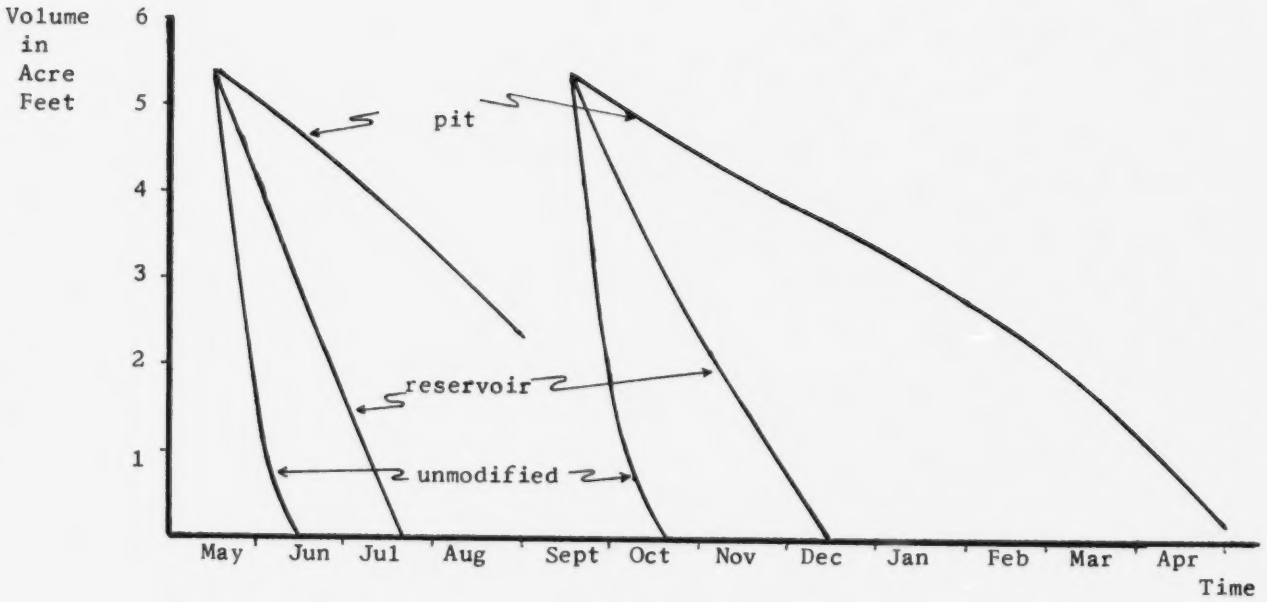


Figure 5: Volume Over Time of 8 Acre Lake with Filling Dates of May 15 and Sept 15 -- Medium-Textured Soil Area.

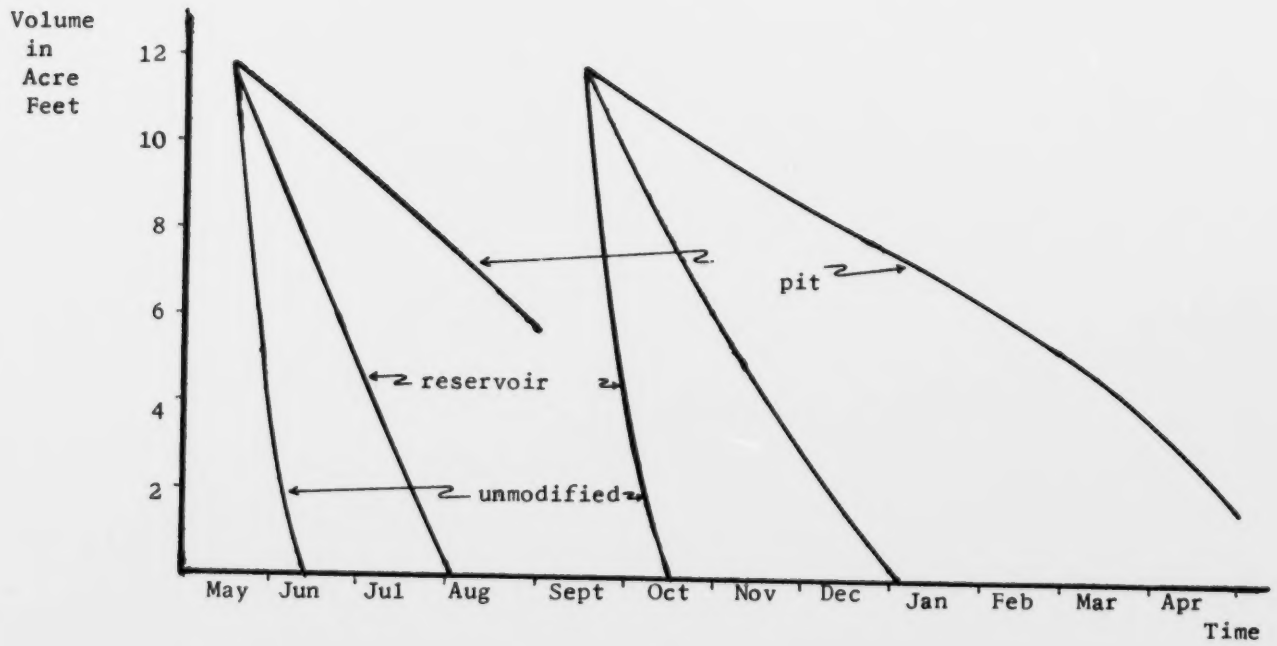


Figure 6: Volume Over Time of 15-Acre Lake with Filling Dates of May 15 and September 15 -- Medium-Textured Soil Area.

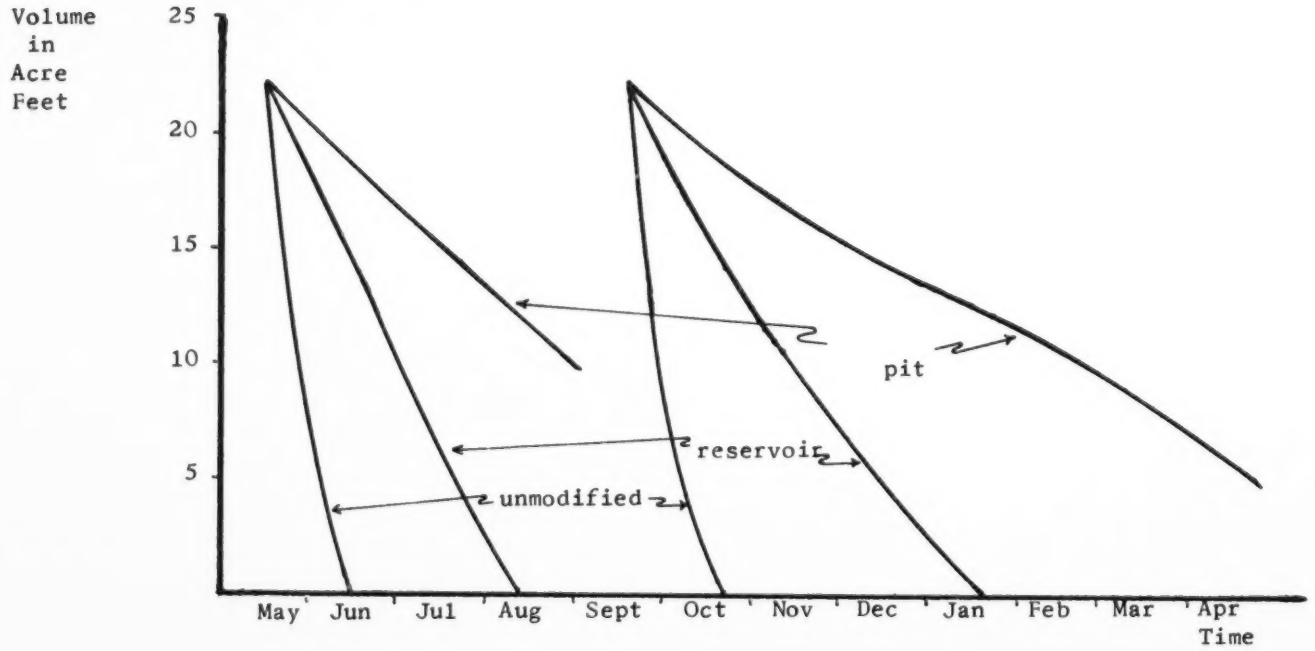


Figure 7: Volume Over Time of 25 Acre Lake with Filling Dates of May 15 and September 15 -- Medium-Textured Soil Area.

## Appendix B

### VOLUME-AREA RELATIONSHIP FOR THE REPRESENTATIVE LAKE SIZES CONSIDERED FOR MODIFICATION

Fine-Textured Soil Area

| | |
|---|---|
| 8 acre lake | $\log_e$ Vol = -3.337716 + 2.740166 $\log_e$ area |
| 15 acre lake | $\log_e$ Vol = -5.129266 + 2.822366 $\log_e$ area |
| 25 acre lake | $\log_e$ Vol = -3.698507 + 2.209634 $\log_e$ area |
| 45 acre lake | $\log_e$ Vol = -1.777376 + 1.541161 $\log_e$ area |

Medium-Textured Soil Area

| | |
|---|---|
| 8 acre lake | $\log_e$ Vol = -2.273453 + 2.024194 $\log_e$ area |
| 15 acre lake | $\log_e$ Vol = -3.993845 + 2.024083 $\log_e$ area |
| 25 acre lake | $\log_e$ Vol = -4.499977 + 2.299809 $\log_e$ area |

### Cost of Pumping Lake Water

The cost of pumping lake water was determined by adjusting the minimum acre-foot pumping cost of Reddell's irrigation water recirculating system ($6.50 per acre-foot) by the 15 percent decrease in cost of a recirculating system without a one and one-half acre-foot sump.

$$\frac{(\$6.50 \text{ per acre-foot}) \quad (85 \text{ percent})}{12 \text{ inches per foot}} = 46 \text{ cents per acre inch.}$$

# APPENDIX C

# MODIFICATION MODELS

Appendix C

MODIFICATION MODELS

Model I. -- The Model I modification consisted of a sump constructed near the perimeter of the lake and included a trench to drain water from all points of the lake into the sump (Figure 1). The number of cubic yards excavated from the sump ($X_{11}$) depended upon the sump depth. Sump specifications were as follows:

$L'W' = 50$ square feet

$L' = 2W'$

$L = L' + 4d$

$W = W' + d$

where:

$L'$ = length of sump bottom in feet

$L$ = length of sump top in feet

$W'$ = width of sump bottom in feet

$W$ = width of sump top in feet

$d$ = depth of sump = two feet plus lake depth

Under these conditions, the quantity of earth moved was as follows:

$$X_{11} = \frac{50d + 15d^2 + 2d^3}{27} \qquad (3)$$

The depth of the various sized lakes in the two soil areas was estimated and the required quantities of earth moved in order to modify lakes were estimated. The volume of the drainage ditch ($X_{12}$) was estimated as follows:

$$X_{12} = \frac{d^2 L''}{27}$$

where

$X_{12}$ = volume of drainage ditch in cubic yards

$d$ = depth of sump

$L''$ = length of trench = $\frac{43{,}560A}{}$

where $A$ = lake surface acres

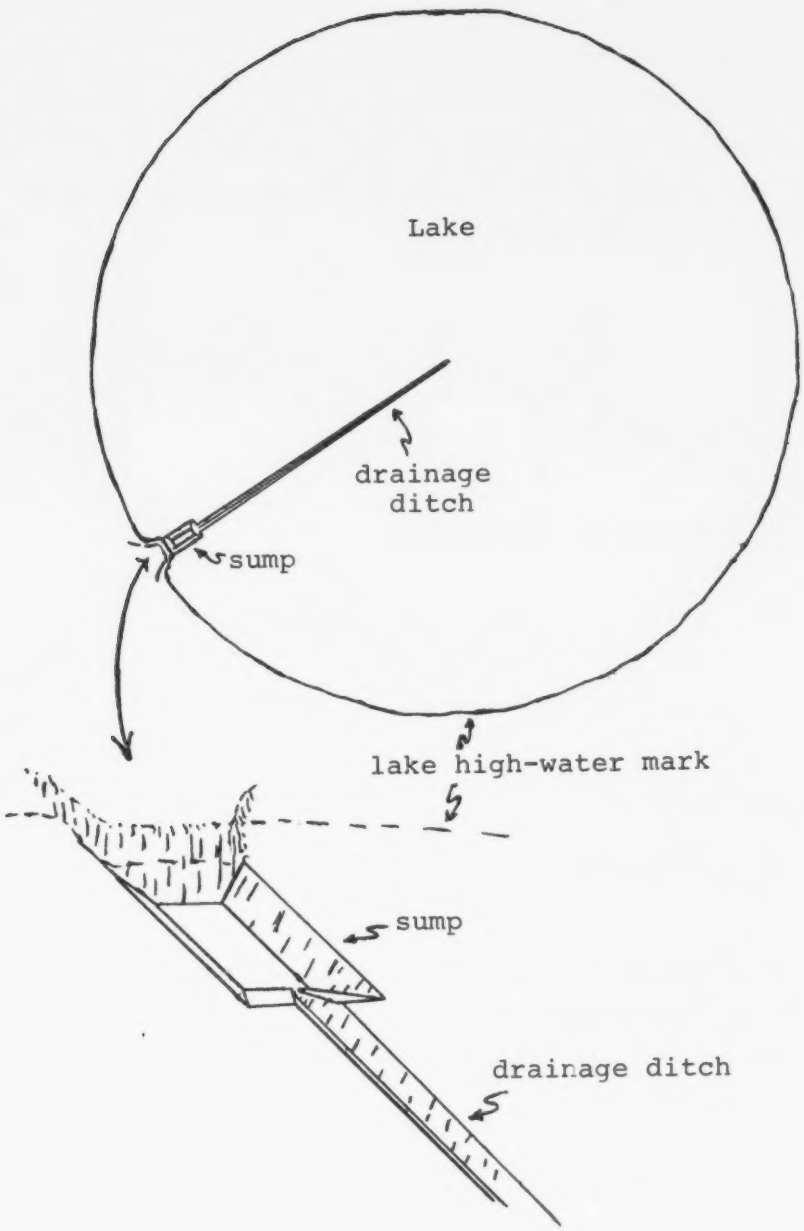


Figure 1--Illustration of Modification Model I

Model II.--The Model II modification was composed of two dykes within the lake and a diversion terrace around the lake to direct water into dyked areas (Figure 2). One of the dykes was constructed along a diameter of the lake and divided the lake into two equal parts. The second dyke was constructed perpendicular to the first dyke and formed two-one-quarter sections of the lake. The modification would be arranged so as to fill one-quarter section of the lake directly from the diversion terrace and any additional water would be directed through a spillway into the second one-quarter of the lake.

The number of cubic yards of earth moved for the dykes ($X_{12}$) in Model II was dependent upon the lake depth. The total volume of the two dykes was expressed as follows:

$$X_{21} = \frac{4\ hr + h^2 r}{12} \qquad (5)$$

where

$X_{21}$ = volume of the dykes in cubic yards
h = height of dyke = depth of lake plus two feet
r = radius of lake at the high-water mark

The volume of earth moved to build the diversion terrace ($X_{22}$) was expressed as follows:

$$X_{22} = (A)\ (L)$$

where

A = cross sectional area of diversion terrace
L = length of terrace

Model III. -- The Model III modification was a circular reservoir constructed in the lake-bed with an elevated entrance channel leading from a diversion constructed by enclosing a shallow circular sunken pit with a dam constructed from the excavated soil. The volume of earth moved ($X_{31}$) to construct Model III modification was expressed by the following formula:

$$X_{31} = \frac{\pi r'^2\ d + d^2\ L'}{27} \qquad (7)$$

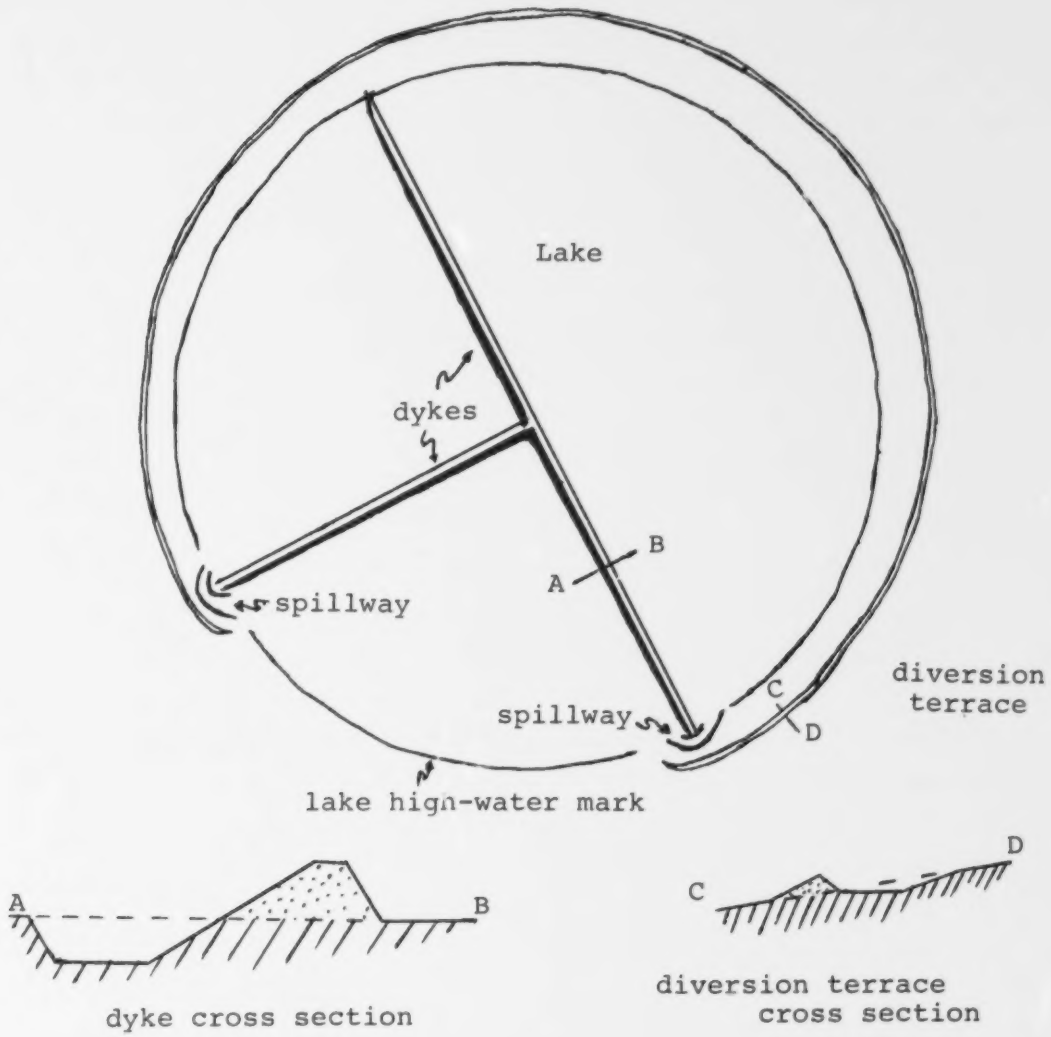


Figure 2--Illustration of Modification Model II

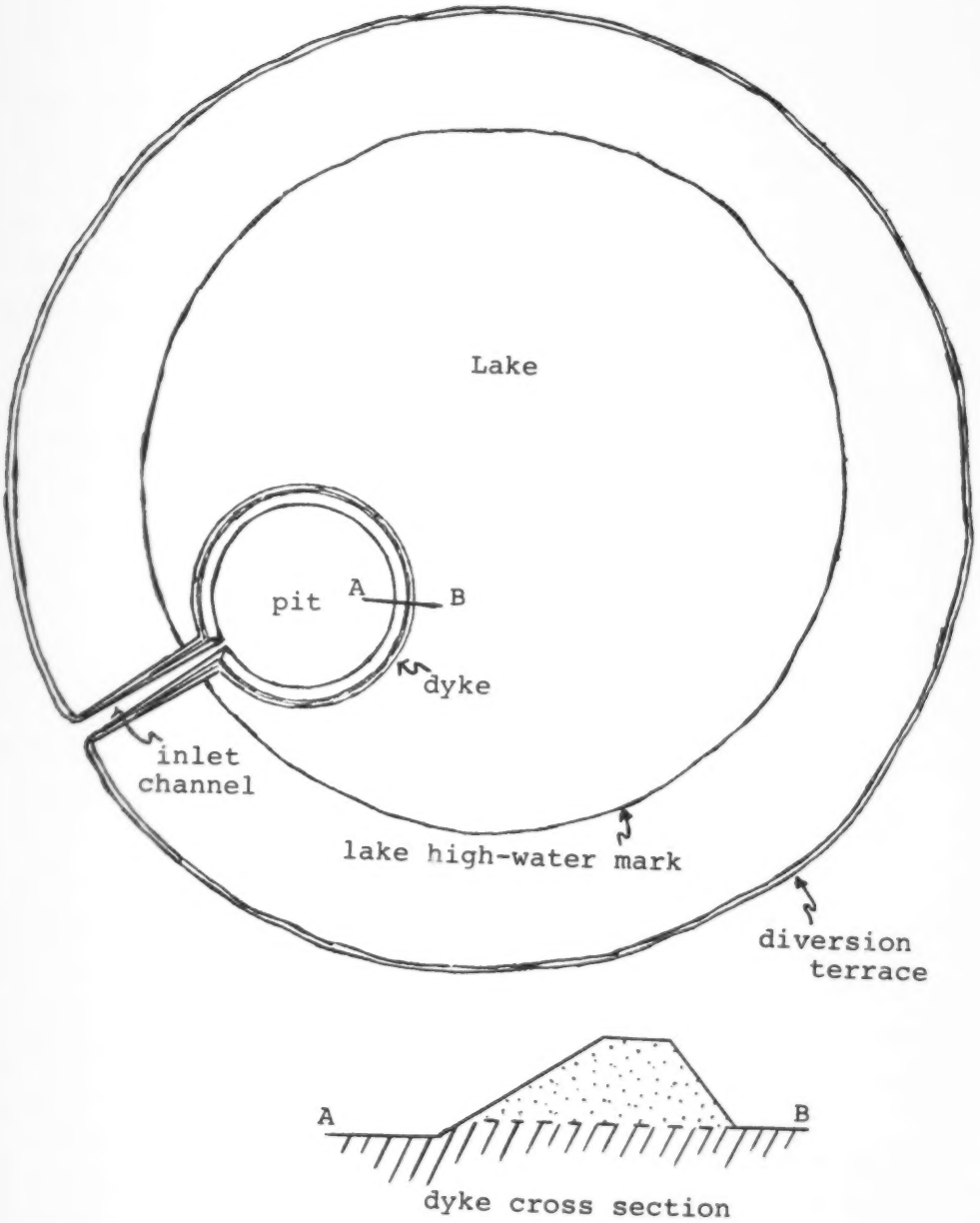


Figure 3--Illustration of Modification Model III

where

$X_{31}$ = volume of earth excavated, in cubic yards

r' = radius of sunken pit bottom, in feet

d = depth of sunken pit, in feet

L' = circumference of sunken pit in feet, where the radius equals r' plus twice the water depth in feet plus two feet.

The volume of earth moved for the diversion system ($X_{32}$) consisted of the sum of the volumes for construction of the diversion terrace in the same manner as the diversion terrace of Model II, thus the explanation of $X_{22}$ was applicable (equation 6).

The number of cubic yards moved to construct the inlet channel was estimated as follows:

$$V = \frac{\left[a_1 + a_2\right] L}{27} \qquad (8)$$

where

V = soil volume, of the two dykes that formed the canal, in cubic yards

$a_1$ = cross sectional area of dyke adjoining terrace, in square feet

$a_2$ = cross sectional area of dyke adjoining pit, in square feet

L = length from diversion terrace to pit, in feet.

Model IV.--The Model IV modification was a rectangular pit constructed in the lake bottom with a raised bank or dyke around the excavation. This modification would receive runoff water directly from the lake-bed instead of from diversion terraces such as those used by Models II and III.

The volume of earth moved in the construction of modification Model IV equalled the desired water volume of the pit; i.e, one cubic yard of earth removed created one cubic yard of storage.[4] The volume was expressed by

[4]The pit specifications were designed to have the following characteristics (1) a surface area equal to one-tenth of the unmodified lake area and (2) end slopes of 6:1 and side slopes of 1:1.

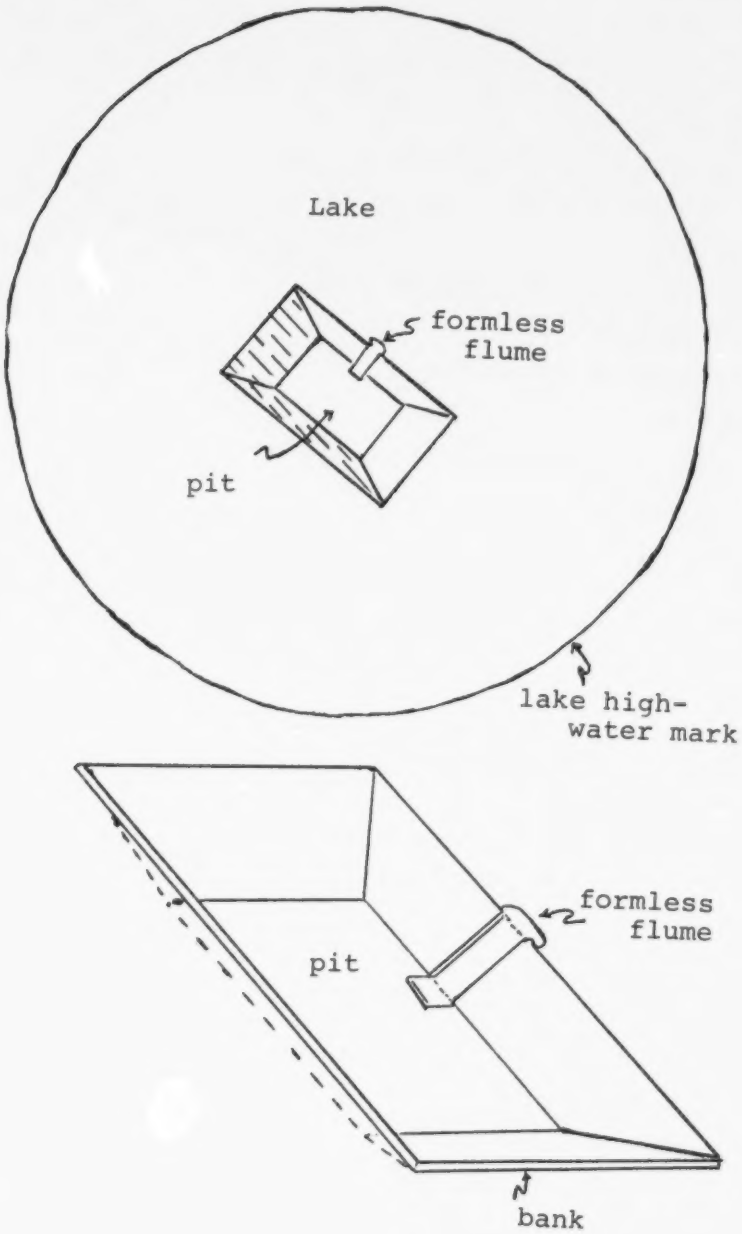


Figure 4--Illustration of Modification Model IV

the following formula:

$$X_{41} = \frac{(LW) + (L'W')}{2} \quad \frac{h}{27} \qquad (9)$$

where

$X_{41}$ = volume of pit, in cubic yards

W' = width of pit bottom, in feet

L'= length of pit bottom, in feet

L = length of pit top = L' + 12h

W = width of pit top = W' + 2h

h = depth of pit in feet

L' = 4W'

LW = pit surface area, in square feet